DOCUMENT RESUME

ED 447 267 CE 080 777

AUTHOR	Dobson, Michael B.
TITLE	Anaesthesia at the District Hospital. Second Edition.
INSTITUTION	World Health Organization, Geneva (Switzerland).
ISBN	ISBN-92-4-154527-5
PUB DATE	2000-00-00
NOTE	165p.; Published in collaboration with the World Federation of Societies of Anaesthesiologists. Illustrated by Derek Atherton and Elisabetta Sacco.
AVAILABLE FROM	World Health Organization Publications Center USA, 49 Sheridan Avenue, Albany, NY 13210; Tel: 518-436-9686; Fax: 518-436-7433; e-mail: Qcorp@compuserve.com (Order No. 1152289, $31.50; 24.50 Swiss francs in developing countries).
PUB TYPE	Guides - Non-Classroom (055)
EDRS PRICE	EDRS Price MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	*Anesthesiology; Biomedical Equipment; Check Lists; Drug Use; Guides; *Hospitals; *Medical Education; Medical Services; Pain; Professional Continuing Education; Surgery

ABSTRACT

This practical manual is designed to help medical officers in small hospitals provide safe and effective anesthesia for patients. Intended for doctors with at least one year of postgraduate clinical experience, it describes anesthetic techniques suitable for use in hospitals with limited resources. Chapter 2 describes fundamental principles and techniques underlying the practice of anesthesia and outlines immediate and continuing care of critically ill or unconscious patients. Chapter 3 focuses on continuing care of unconscious and anesthetized patients. The focus of Chapter 4 is on the principles of fluid and electrolyte therapy. Chapters 5 and 6 cover patient assessment before anesthesia and general anesthesia. Chapter 7 concerns safe clinical use of anesthetic equipment best-suited for and most likely found in district hospitals. Chapter 8 contains examples of general anesthetic techniques feasible in small or medium-sized hospitals. Chapter 9 provides information on drugs. Chapter 10 suggests techniques for conduction anesthesia. Chapters 11 and 12 discuss choosing and planning the anesthetic technique and postoperative care of the patient. Chapters 13 and 14 discuss special needs of pediatric and obstetric anaesthesia and important medical conditions. Chapter 15 covers oxygen, gas supplies, equipment, and maintenance. Numerous illustrations convey technical details; tables, charts, and checklists summarize lines of action and points to remember. Checklists and an index are appended. (YLB)

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Second edition

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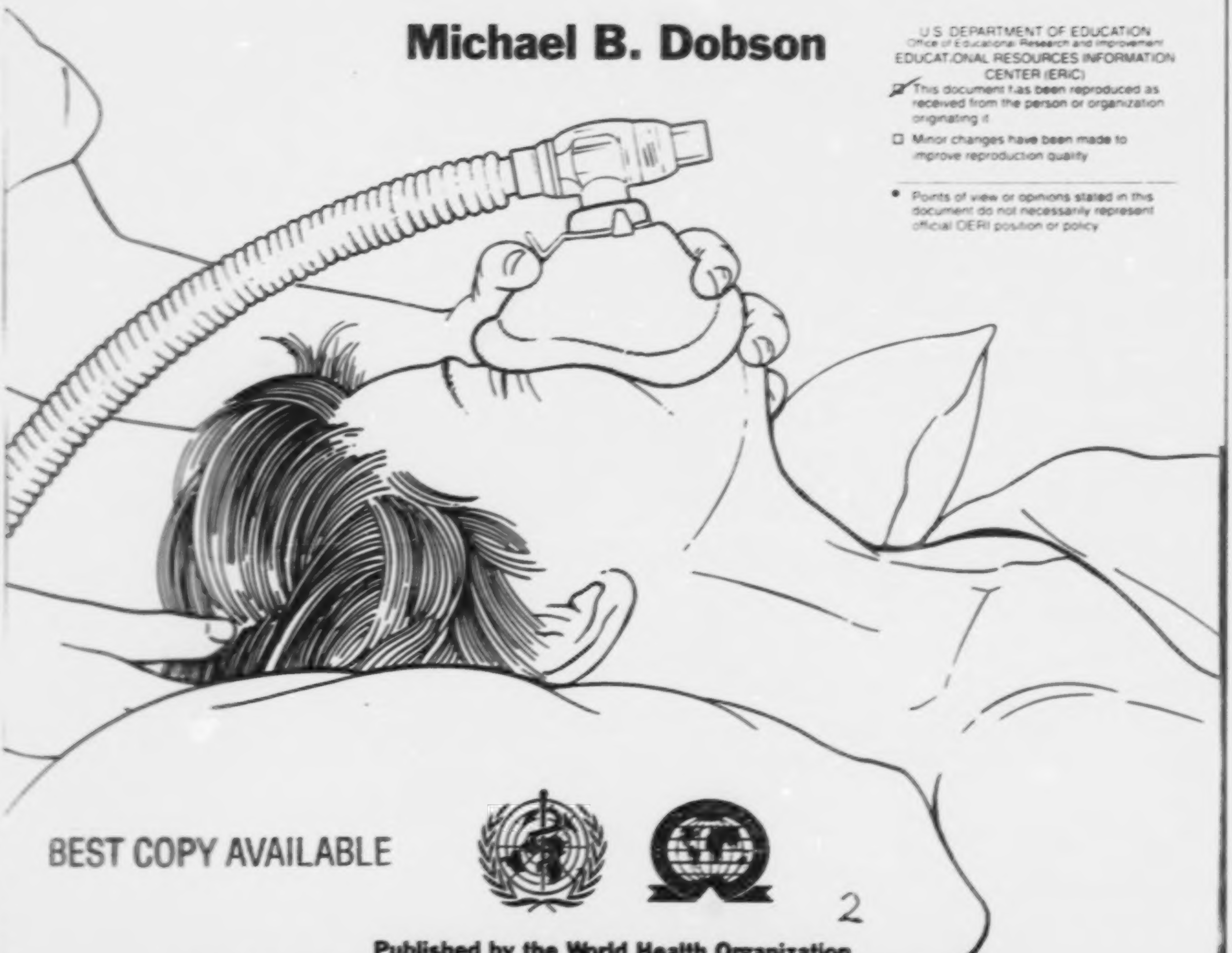

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Anaesthesia at the district hospital

Second edition

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World Health Organization
Geneva
2000

WHO Library Cataloguing-in-Publication Data

Dobson, Michael B.
Anaesthesia at the district hospital/Michael B. Dobson; illustrated by Derek Atherton and Elisabetta Sacco — 2nd ed.

Published in collaboration with the World Federation of Societies of Anaesthesiologists.

1.Anesthesia — methods 2.Hospitals, District 3.Manuals
I.Title

ISBN 92 4 154527 5 (NLM Classification: WO 200)

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The author alone is responsible for the views expressed in this publication.

Typeset in Hong Kong
Printed in Bahrein
98/12347 — Best-set/Oriental — 8000

CONTENTS

Preface to the second edition v
Preface to the first edition vi

1 **Introduction** 1

2 **Fundamental techniques and skills** 3
- Assessment of the critically ill and/or unconscious patient 3
- Care of the airway 4
- Failed intubation 10
- Care of the patient whose breathing is inadequate 15
- Management of the circulation 17
- Assessing the effects of treatment 19
- Transportation of the critically ill patient 20
- When to abandon resuscitation 21
- The severely injured patient 21

3 **Care of unconscious and anaesthetized patients** 25
- General management 25
- Respiratory function in the anaesthetized patient 26
- The cardiovascular system 31
- Management of unexpected cardiorespiratory arrest 33

4 **Principles of fluid and electrolyte therapy** 36
- Fluid compartments of the body 36
- Fluid therapy 38
- Clinical assessment of fluid status 39
- Estimation of blood losses during surgery and the need for blood transfusion 40
- Specific losses and replacement 42
- Production of sterile fluids for intravenous use 43

5 **Assessing the patient before anaesthesia** 44
- Examining the patient 44
- Preoperative fasting and fluids 46
- Premedication for anaesthesia and surgery 46

6 **General anaesthesia** 50
- Before induction of anaesthesia 51
- Intravenous induction 52
- Intramuscular induction 53
- Inhalational induction 54

7 **Clinical use of anaesthetic equipment** 57
- Draw-over apparatus 57
- Continuous-flow machines 68

8 **Specimen general anaesthetic techniques** 73
Levels of anaesthetic services 73
Ketamine anaesthesia 73
General inhalational anaesthesia 74
Techniques of total intravenous anaesthesia 76
General anaesthesia for emergency cases 76

9 **Drugs used in general anaesthesia** 79
Inhalational agents 79
Other volatile anaesthetic agents 80
Intravenous anaesthetics 81
Benzodiazepines 82
Opiate drugs 83
Non-steroidal anti-inflammatory drugs (NSAIDs) 83
Muscle relaxant drugs 83

10 **Conduction anaesthesia** 86
Toxicity and safety of local anaesthetic drugs 86
Contraindications to conduction anaesthesia 87
General precautions and basic equipment 88
Sedation during conduction anaesthesia 88
Specimen techniques 88

11 **Choosing and planning your anaesthetic technique** 103
Choice of anaesthetic technique for a particular operation 103
Planning general anaesthesia 104
Safety of general and conduction techniques 106

12 **Postoperative care of the patient** 107

13 **Paediatric and obstetric anaesthesia** 109
Anaesthesia for children 109
Anaesthesia during pregnancy and for operative delivery 113
Resuscitation of the newborn infant 115

14 **Important medical conditions for the anaesthetist** 118
Anaemia 118
Haemoglobinopathies 119
Cardiovascular diseases 120
Respiratory diseases 122
Diabetes 124
Obesity 125
Malnutrition 125
Chronic renal failure 126
Transmission of infection during anaesthesia and surgery 126

15 **Oxygen, gas supplies, equipment, and maintenance** 128
Gas supplies 128
Minimum anaesthetic equipment for district hospitals 133
Storage and maintenance of equipment 134

Annex 1 Checklist for draw-over anaesthetic apparatus 137

Annex 2 Checklist for continuous-flow (Boyle's) anaesthetic apparatus 139

Annex 3 Anaesthesia record 141

Annex 4 Drugs used in anaesthesia 143

Index 145

Preface to the second edition

Response to the first edition of this book published by WHO in 1988 has been extremely good. In the years since it was written, positive feedback has come from readers, journal reviews, and WHO workshops. Changes in availability of equipment and drugs, together with changes in emphasis in clinical practice, make a new edition necessary — particularly since the book is aimed primarily at non-specialist anaesthetists who may not have access to other means of keeping up to date.

Most of the original wonderfully clear line drawings have been retained, and a few more have been added. There is a revised and expanded chapter on fundamental skills, with further advice on airway safety and inclusion of the widely used Glasgow Coma Scale for assessment of patients with head injuries. Resuscitation guidelines have been updated in accordance with the latest recommendations for advanced life support. Increased awareness of the risks as well as benefits of blood transfusions has brought a new stress on their safe and appropriate use in accordance with new WHO guidelines. The descriptions of anaesthetic equipment have been revised to fit more closely the range of equipment most likely to be found at the district hospital. A number of obsolete drugs have been removed, and appropriate alternatives described. Oxygen supplies, and a recommended Performance Standard for oxygen concentrators, are now the subject of a separate chapter. Control of acute pain is given increased emphasis, as is the need for good record-keeping and audit, which give even the most basic hospital the opportunity to review and improve results.

As with the first edition, the overall aim is to present anaesthesia and its related skills in terms that will most help hard-pressed practitioners in district hospitals worldwide to deal effectively and safely with the needs of surgical, severely injured, and critically ill patients. Trained people are the most valuable resource in medicine — if this book helps to improve the level of training at this level it will have fully achieved its goal.

Michael Dobson

Preface to the first edition

This handbook is one of three[1] to be published by the World Health Organization for the guidance of doctors providing surgical and anaesthetic services in small district hospitals (hospitals of first referral) with limited access to specialist services. The advice offered has been deliberately restricted to procedures that may need to be carried out by a young doctor with limited experience in anaesthesia, surgery, or obstetrics, using the facilities that can reasonably be expected in such hospitals. Wherever possible, the drugs, equipment, and radiodiagnostic and laboratory procedures described conform with WHO and UNICEF recommendations.

Although the handbooks contain detailed descriptions and illustrations, the advice they offer is no substitute for practical experience. The reader is expected to have been exposed to all the relevant techniques during undergraduate or early postgraduate education. When necessary the text indicates which patients should be referred for specialized care at a higher level, as it is important to developing health services that young doctors and their supervisors understand the limitations of practice at the district hospital.

It has, of course, been necessary to be selective in deciding what to include in the handbooks, but it is hoped that any important omissions will be revealed during field testing. WHO would also be pleased to receive comments and suggestions regarding the handbooks and experience with their use. Such comments would be of considerable value in the preparation of any future editions of the books. Finally, it is hoped that the handbooks will fulfil their purpose — to help doctors working at the front line of surgery throughout the world.

The three handbooks have been prepared in collaboration with the following organizations:

Christian Medical Commission
International College of Surgeons
International Council of Nurses
International Federation of Gynaecology and Obstetrics
International Federation of Surgical Colleges
International Society of Burn Injuries
International Society of Orthopaedic Surgery and Traumatology
League of Red Cross and Red Crescent Societies
World Federation of Societies of Anaesthesiologists
World Orthopaedic Concern.

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[1] See *General surgery at the district hospital* (Geneva, World Health Organization, 1988) and *Surgery at the district hospital: obstetrics, gynaecology, orthopaedics, and traumatology* (Geneva, World Health Organization, 1991). See also *Rehabilitation surgery for deformities due to poliomyelitis: techniques for the district hospital* (Geneva, World Health Organization, 1993).

Acknowledgements

This handbook has been prepared as part of a collaborative activity between WHO and the World Federation of Societies of Anaesthesiologists (WFSA), which reviewed and endorsed the draft manuscript and illustrations. In this regard, the support of Dr John Zorab, former President and Secretary, WFSA, is gratefully acknowledged.

1
Introduction

This volume has been produced to help medical officers in small hospitals to provide safe and effective anaesthesia for their patients. Because the resources available for health care are limited, especially in these small hospitals, many anaesthetic services are subject to constraints on personnel, equipment, and drugs. An anaesthetic service must therefore strike a balance that meets most clinical needs most of the time, rather than strive for perfection in some areas while neglecting others. Difficulty in obtaining sufficient supplies, particularly of items that must be imported, may mean that there are no reserves of drugs or spare equipment in the hospital. Anaesthetic techniques for such a hospital should therefore depend as little as possible on external supplies and technology (equipment, expertise for maintenance work, etc.). The needs of a small hospital are best served by the regular use of relatively few anaesthetic techniques that can provide good anaesthesia for virtually any clinical situation. This book is intended to be a manual of such techniques.

Anaesthesia is now much safer and more pleasant for the patient than it was 50 years ago. Factors contributing to the improvements include a fuller understanding of physiology and pharmacology; better preoperative assessment and preparation of patients; closer monitoring of anaesthetized patients; and the introduction of new techniques, such as the use of muscle relaxants, tracheal intubation, and calibrated vaporizers for volatile anaesthetic agents. Improvements in anaesthesia have allowed surgeons to attempt more complicated operations on increasing numbers of patients, and this has resulted in a growing demand for and a shortage of anaesthetists. In many small hospitals a specialist anaesthetist will not be available, and anaesthesia will be the responsibility of a medical officer with one or two years of postgraduate training, who will need to provide anaesthesia not only for routine elective surgery but also for emergency surgery requiring more major procedures, when a life-threatening condition prevents referral of the patient to a larger hospital. A medical officer who is thoroughly familiar with a small clinical repertoire of safe anaesthetic techniques will be well equipped to deal with both elective and emergency cases.

Every anaesthetist needs a foundation of basic medical science for his or her clinical techniques. A sound knowledge of physiology and pharmacology is essential, together with an understanding of the changes brought about by illness or injury. However, these subjects are normally dealt with during undergraduate training and are beyond the scope of this short book.

Many techniques originally developed for use during anaesthesia are now widely recognized as applicable to the care of a variety of critically ill patients, for example those with severe head injuries, asthma, tetanus, or neonatal asphyxia. Skills such as the rapid assessment and management of unconscious patients, control of the airway, tracheal intubation, management of the circulation, and cardiopulmonary resuscitation have their origins in anaesthesia, but are now recognized as essential for all doctors.

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Good anaesthesia depends much more on the skills, training, and standards of the anaesthetist than on the availability of expensive and complicated equipment. Even if it is difficult to obtain medical gases, a small hospital must still provide an anaesthetic service. This can be achieved by the use of draw-over anaesthetic techniques, in which ambient air is used as the carrier gas to which volatile anaesthetic agents are added by calibrated, low-resistance vaporizers. If oxygen is available, it can be used to enrich the inspired gas mixture, but it is not essential; nitrous oxide, which is harder to obtain and more expensive than oxygen, is unnecessary. Draw-over techniques are capable of producing first-class clinical anaesthesia; the apparatus is simple to understand and use, and can usually be serviced locally. Compared with systems dependent on compressed medical gases, draw-over systems are economical in use and have added safety in that the lowest oxygen concentration that can be delivered is that of air. Draw-over anaesthesia is the system of first choice for small hospitals; it should also be in regular use in larger and teaching hospitals as one of a range of techniques. Since some small hospitals are already equipped with continuous-flow (Boyle's) anaesthetic apparatus, its use is also covered in this manual. Continuous-flow machines require compressed medical gases for use, and great care is needed to avoid the accidental delivery of hypoxic gas mixtures to the patient.

Techniques of conduction (local or regional) anaesthesia are also described here, though they are best learned from practical clinical teaching. It is a common mistake to believe that general anaesthesia is "dangerous" and conduction anaesthesia "safe". Conduction anaesthesia has a valuable and important place in anaesthesia, but requires the same care and attention to the preparation and selection of patients as does general anaesthesia, because serious adverse reactions can and do occur.

Anaesthesia is a practical clinical subject as well as an academic study. This manual alone cannot teach you to be a safe and skilled anaesthetist — no book could. A period of clinical teaching under the close supervision of an experienced anaesthetist is essential, both at the beginning of training and at regular intervals thereafter. Such training can be arranged either by attachment of medical officers to larger hospitals or by organizing regular visits by specialist anaesthetists to smaller hospitals. Experience can also be a good teacher, and the best way to make use of it is to keep a careful record of every anaesthetic given and to review these records with colleagues at regular intervals. No hospital is too small to benefit from regular clinical reviews and no doctor too wise to benefit from the experience of colleagues.

This is a limited book with limited aims. Readers who decide to become specialist anaesthetists will ultimately find its range of techniques too restrictive and will move on to more extensive textbooks, but the basic principles of safe anaesthesia set out here will continue to serve them well.

2

Fundamental techniques and skills

With the establishment of anaesthesia as a major medical speciality over the last 60 years, a number of anaesthesia-related skills have emerged. These skills were originally used primarily in the care and protection of anaesthetized patients, but they are now recognized as essential for all doctors who deal with unconscious or critically ill patients, and are particularly important for those working in small hospitals who may have to bear responsibility for all aspects of a patient's welfare and management. The range of such skills includes:

- assessment of the critically ill and/or unconscious patient
- care of the airway
- care of the patient whose breathing is inadequate
- management of the circulation
- assessment of the effects of treatment
- transportation of the critically ill patient.

Once acquired, these skills are relevant both to the immediate care of a variety of critically ill patients — for example, those with severe dehydration, head injury, or major blood loss — and to the proficient and safe practice of clinical anaesthesia.

Assessment of the critically ill and/or unconscious patient

To identify any immediate threat to life and start treatment, you must be able to make a brief and rapid assessment of a patient who is critically ill. In many cases the cause of the patient's condition is obvious, but it may help you to remember the letters A-B-C-B-A:

A — Airway
B — Breathing
C — Circulation
B — Brain
A — Assess other injuries.

This initial assessment should take only a few moments:

A — Check whether the patient has a clear airway.
B — Check whether the patient is breathing; if not, he or she will need immediate artificial ventilation.
C — Check for pulsation in a major vessel (carotid or femoral arteries); if there is a circulatory arrest, start external cardiac massage immediately.
B — Assess the patient's brain function; note responses to speech, stimulation, or pain, and also pupillary size and any abnormal posture.
A — Rapidly assess any associated injuries, including "hidden" ones such as a pneumothorax or pelvic fracture, and estimate the extent of blood loss or fluid depletion.

Once you have made your rapid assessment, you may decide that one or more aspects of the patient's condition demand priority. Their management is outlined below

Care of the airway

Any severely injured or unconscious patient lying supine is in extreme danger of airway obstruction and asphyxiation. The tongue falls backwards in this position, causing partial or complete obstruction of the pharynx. Airway obstruction of this type is by far the commonest cause of preventable death after head injury. First check the mouth and pharynx for the presence of any foreign body. Once this is done, and provided that the patient is breathing and there is no contraindication to movement (such as suspected spinal injury), turn him or her over into the semiprone or coma position with the upper arm and leg flexed. If it is not possible to turn the patient, for example during anaesthesia, the airway may be kept clear by one of the following means.

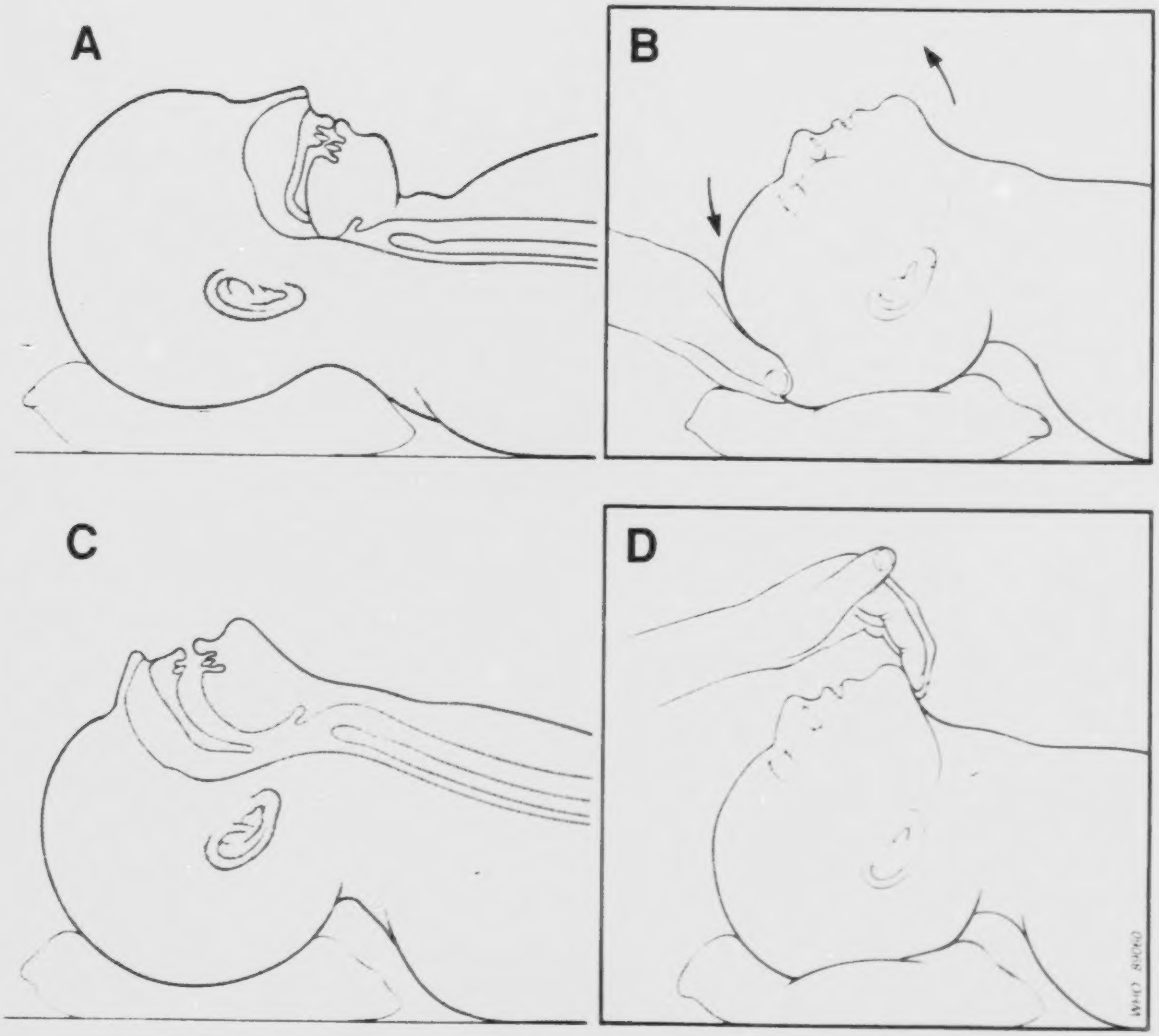

Fig. 2.1. Clearing the airway by extension of the head. (A) Mechanism of airway obstruction when supine; (B, C) extension of the head; (D) maintaining a clear airway by supporting the jaw.

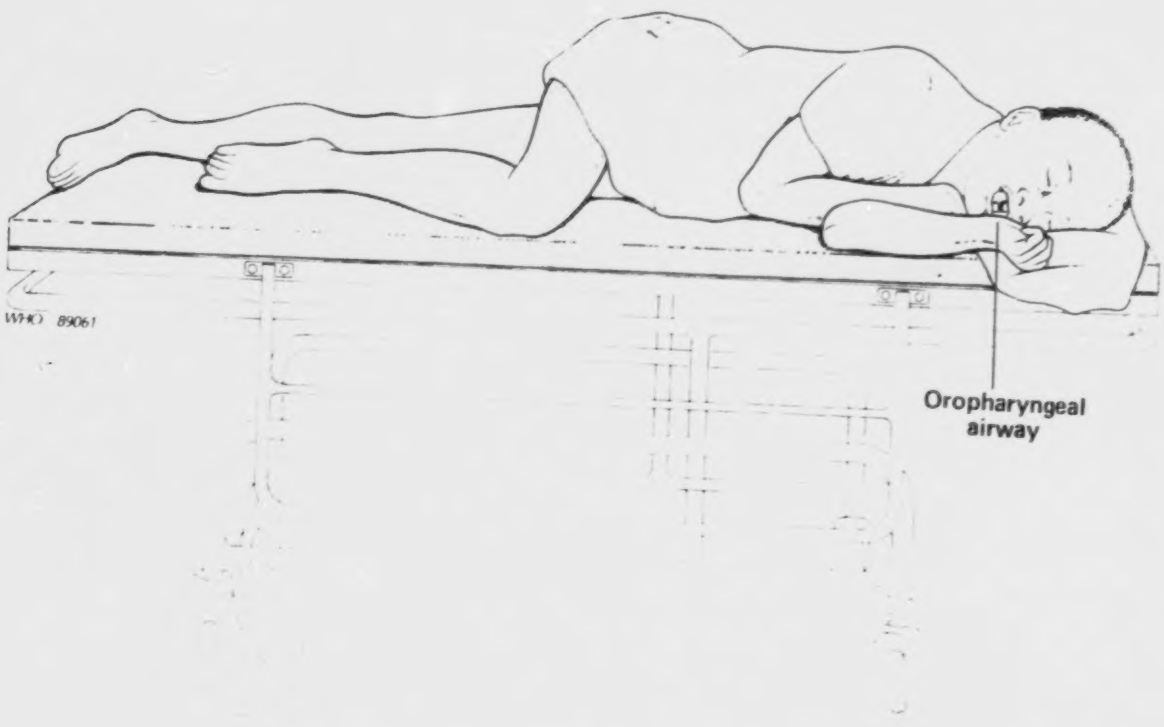

Fig. 2.2. The use of an oropharyngeal airway with the patient in the semiprone (coma) position.

Repositioning the head and neck

Extension of the head combined with forward displacement of the jaw (which lifts the tongue forward by its attachment to the jaw) will often clear the airway (Fig. 2.1).

Inserting an artificial airway

An oropharyngeal or nasopharyngeal airway will help to maintain a clear air passage (Fig. 2.2 & 2.3). An oropharyngeal airway should be lubricated before insertion with lubricating gel or water, but never liquid paraffin (mineral oil). Insert it with the concave side facing upwards, and then rotate it into its final position as it enters the pharynx. In a patient with tightly clenched teeth, a nasopharyngeal airway is sometimes helpful; insert it gently to avoid causing a nosebleed. If a nasal airway is not available, insert a tracheal tube through the nose until its tip lies just above the tip of the epiglottis. Do not use gags and wedges to force open a patient's mouth; they are damaging and potentially dangerous. A patient whose mouth is firmly closed can be managed either in the coma position if intubation is not possible or, preferably, by tracheal intubation using a relaxant.

Recently a new device, the laryngeal mask airway (Fig. 2.4), has been introduced. It usually provides a clear airway, and may be very helpful in patients who are difficult to intubate. It does not give any protection against aspiration of gastric contents into the lungs, so its usefulness in emergency situations (where the stomach is often full) is limited.

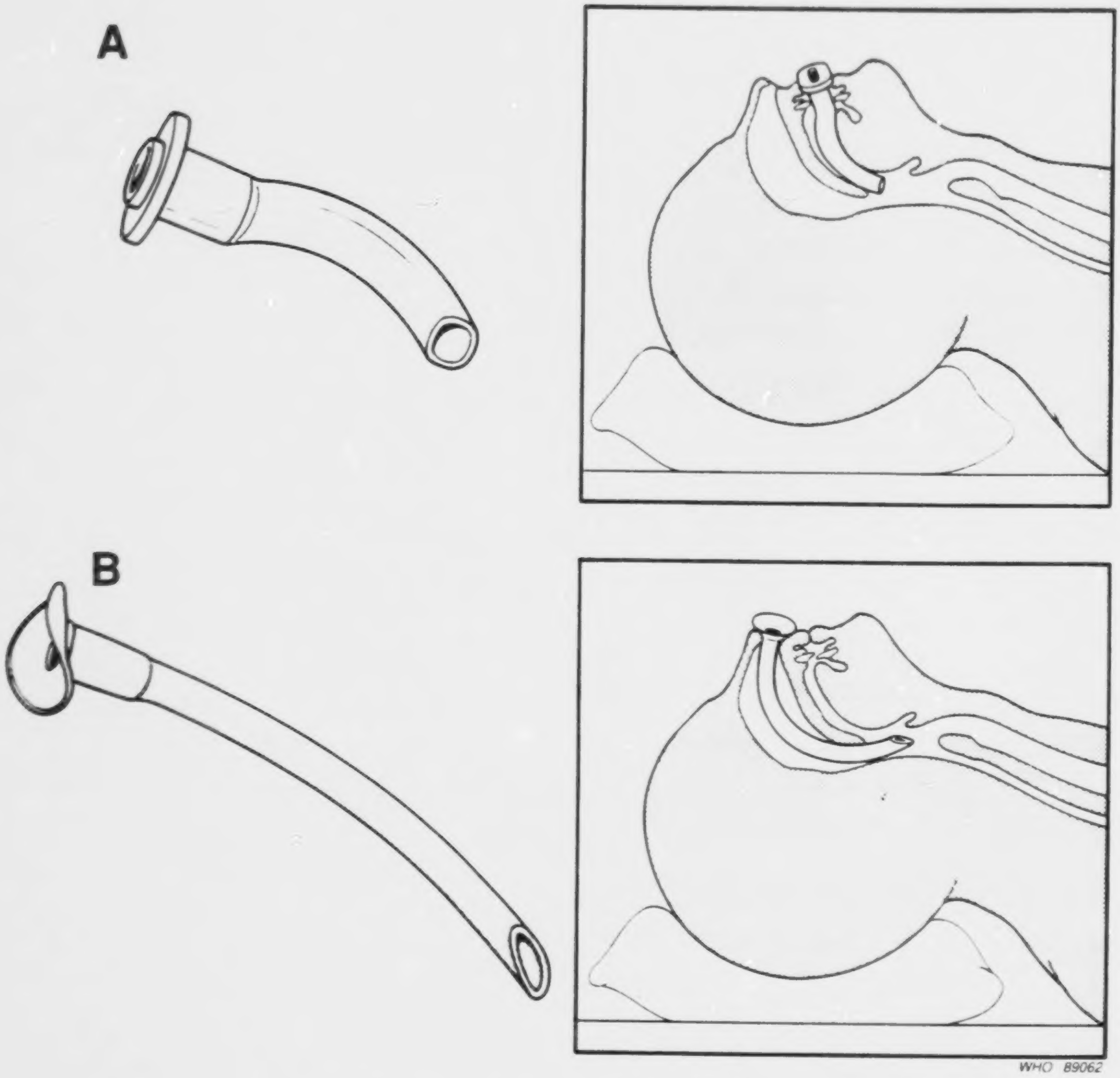

Fig. 2.3. The use of oropharyngeal (A) and nasopharyngeal (B) airways.

Tracheal intubation

The insertion of a tracheal tube provides a clear airway and protects the patient's lungs against the aspiration of gastric contents. Inserting a tracheal tube is not particularly difficult, and every doctor should be capable of performing this life-saving manoeuvre. The technique is now widely taught to doctors, nurses, anaesthetic assistants, and ambulance crews, and once you have mastered it you should teach it to others also.

Tracheal intubation can be performed in the following circumstances:

- conscious patients — suitable for neonates and certain adult emergencies
- unconscious patients — no preparation needed
- anaesthetized patients — light anaesthesia, with a relaxant
  — deep anaesthesia, without a relaxant.

If you are inexperienced, it is much safer to intubate without giving a relaxant, since if intubation fails the patient can still breathe.

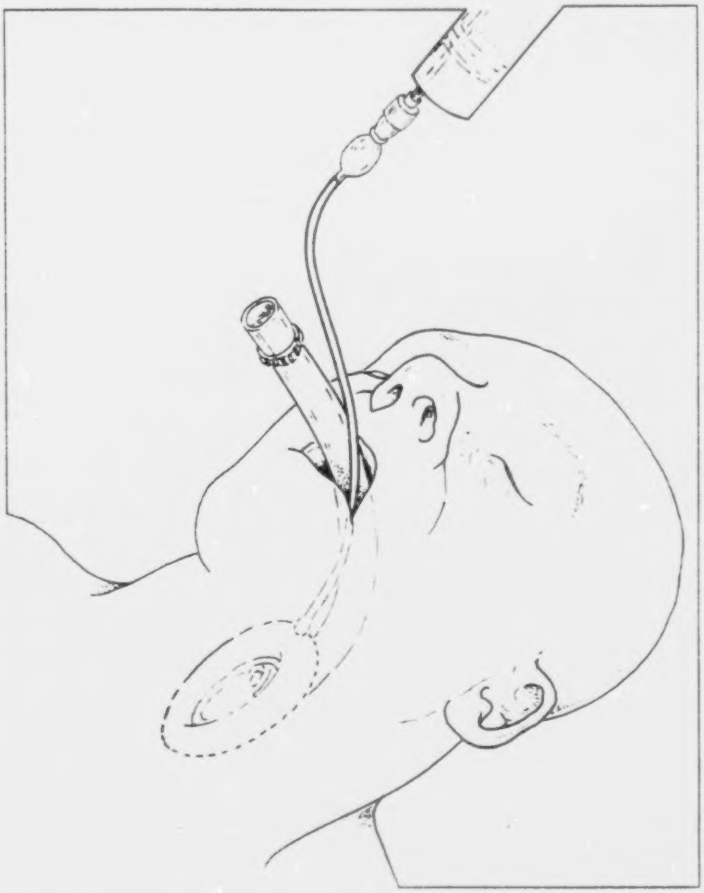

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Fig. 2.4. The laryngeal mask airway.

Technique of tracheal intubation

You will need a trained assistant and the following basic equipment (some of which is shown in Fig. 2.5):

- functioning laryngoscope and spare
- suitably sized tracheal tube
- Magill's intubating forceps
- suction apparatus (electric or manual)
- anaesthetic face mask
- means of inflating the lungs with mask or tube, for example a self-inflating bag or bellows (SIB).

Position of the head and neck

The best possible view of the larynx is obtained by having the neck slightly flexed and the head extended on the neck. In most adults this can be achieved by placing one or even two pillows under the head; the different proportions of a child's body mean that for younger children no pillow is needed and that for the neonate it may be necessary to put a small pillow under the shoulders (Fig. 2.6).

Oxygenation

Even if relaxants are not used, the patient's breathing during the process of intubation is likely to be impaired; you should therefore first give the patient oxygen from a closely fitting face mask (Fig. 2.7A) — 10 good breaths are enough. If the patient is not breathing, gently inflate the lungs using a face mask and an SIB. *Never* try to intubate a cyanosed patient without first inflating the lungs a few times with a face mask, even if only air is available.

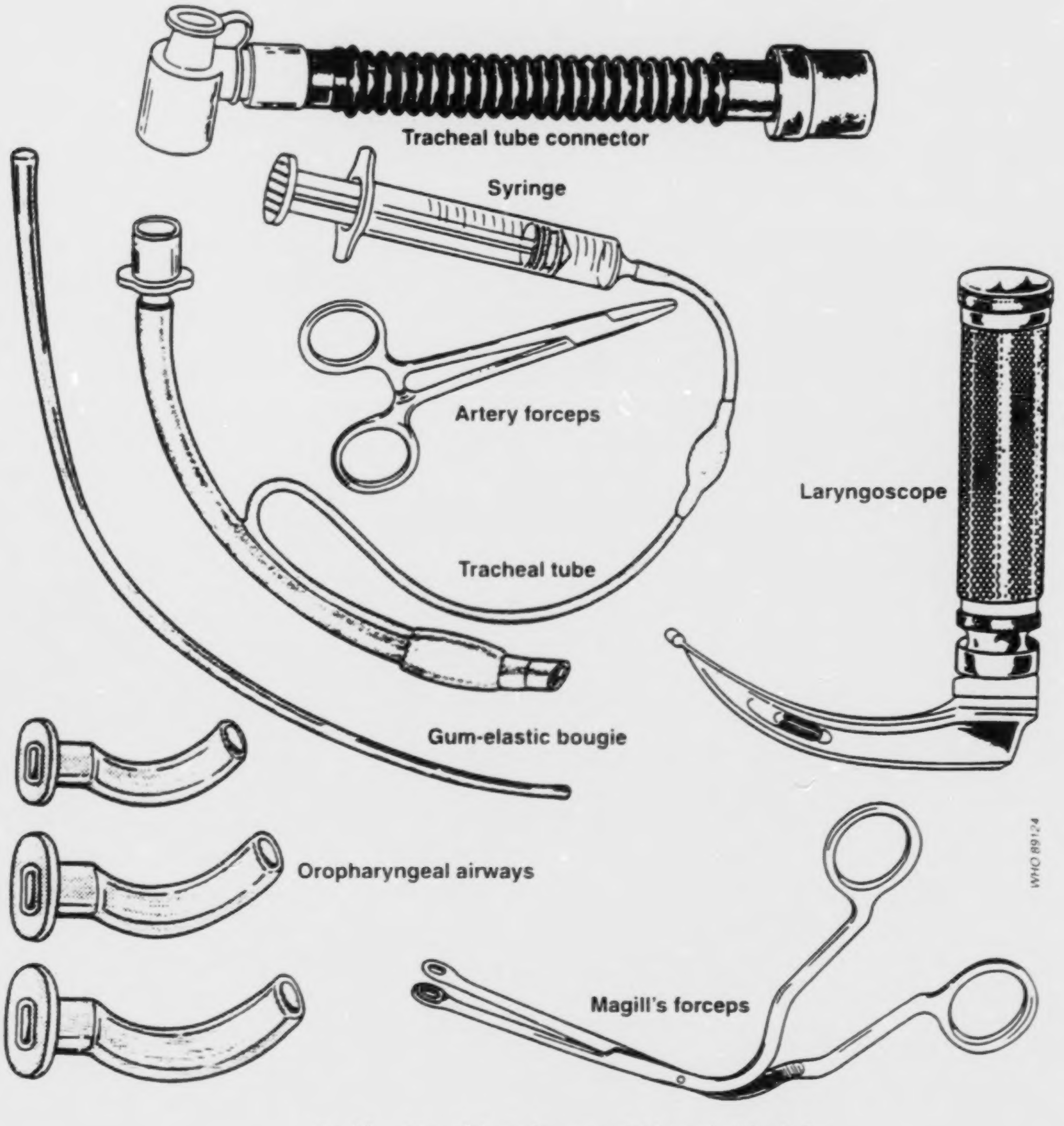
Tracheal tube connector
Syringe
Artery forceps
Laryngoscope
Tracheal tube
Gum-elastic bougie
Oropharyngeal airways
Magill's forceps
WHO 89124

Fig. 2.5. **Some of the equipment needed for tracheal intubation.**

How to use the laryngoscope

Take the laryngoscope in your left hand. Insert the blade gently into the right side of the patient's mouth and pass it back over the tongue until you can see the uvula (Fig. 2.7B–E). (By now the tip of the blade should be in the midline.) Advance the blade a little further, and the tip of the epiglottis will come into view; the blade should pass between the epiglottis and the base of the tongue (Fig. 2.7F, G). Lift the laryngoscope towards the ceiling (do not lever with the patient's front teeth as a fulcrum), and the laryngeal opening will be revealed below and behind the epiglottis, with the white vocal cords visible anteriorly and the arytenoid cartilages posteriorly (Fig. 2.7H–J).

Inserting the tube

Your assistant should now give you the tracheal tube; take it with your right hand, and pass it carefully through the mouth and pharynx (avoid touching the side walls if possible) and between the vocal cords. If you do not have a good view of the cords:

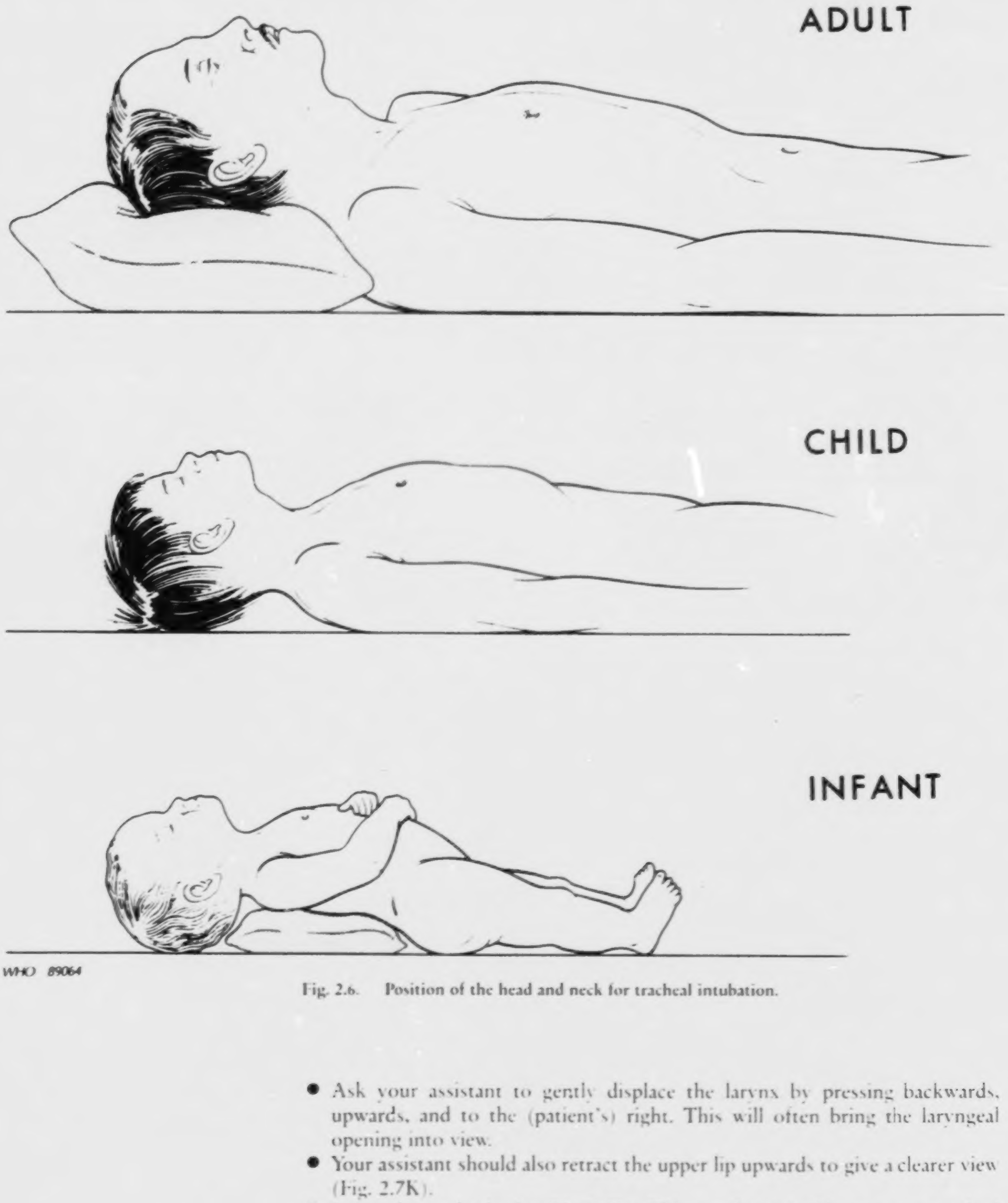

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Fig. 2.6. **Position of the head and neck for tracheal intubation.**

- Ask your assistant to gently displace the larynx by pressing backwards, upwards, and to the (patient's) right. This will often bring the laryngeal opening into view.
- Your assistant should also retract the upper lip upwards to give a clearer view (Fig. 2.7K).
- Insert the tracheal tube (Fig. 2.7L). This may be easier if you pass a urethral bougie down the inside of the tracheal tube with 3–4 cm projecting at the bottom, and a forward curve (Fig. 2.7M). If using Oxford or armoured tracheal tubes you will always need to use a bougie.

Checking the position of the tracheal tube

After intubation it is essential to check the position of the tracheal tube, to ensure that it has passed neither into the oesophagus, nor into one of the main bronchi (which would result in collapse of the opposite lung). The best way to be sure that the tube is not in the oesophagus is to have clearly seen it enter the larynx! Failing this, if the patient is breathing and you can feel breath and hear breath sounds at the top of the tube, it is correctly placed; if the tube is in the oesophagus the patient will breathe around and not through it. If the patient is not breathing (for example if you gave a relaxant) give a sharp tap on the sternum; if the tube is in the trachea you will feel a small puff of air escaping from the tracheal tube. Check by blowing air down the tube with an SIB; if the tube is correctly placed the chest will rise and fall as air enters and leaves, but if the tube is in the oesophagus there is often a gurgling sound and only the stomach will inflate. You should also check the position of the tube by listening with a stethoscope over each lung base and over the stomach while assisting ventilation manually. A further indication of correct intubation is that the non-paralysed patient will often cough if you pass a suction catheter down the tracheal tube.

Once you are sure the tube has entered the trachea, you must check that it has not gone too far and entered a main bronchus. To do this, inflate the lungs manually while listening in turn over both lung apices and both bases. Air entry should be equal on the two sides. If the tube is too far in, it will usually have entered the right main bronchus and there will be no air entry or chest wall movement on the left. If this is so, withdraw the tube 2–3 cm and listen again until air entry is uniform. Once you are certain that the tracheal tube is correctly positioned, fix it securely in place (Fig. 2.7N).

Remember that it is much safer for an inexperienced person to intubate without giving the patient relaxants, since if intubation fails the patient will still be able to breathe. Table 1 gives ten tests that can be rapidly performed to check whether intubation has been successful.

The golden rule of intubation

If at the end of the procedure you are not certain of the position of the tip of the tube, you must remove it and begin again. Remember, all anaesthetists accidentally intubate the oesophagus occasionally, and this need not be harmful as long as it is recognized immediately. It is unrecognized oesophageal intubation that is likely to kill the patient. *If in doubt, take it out!*

Failed intubation

Every anaesthetist, no matter how experienced, has difficulty with intubation on occasion, although the occasions become rarer with increasing experience. You may have little time to spare before attempting emergency intubation of a severely injured or unconscious patient. However, if you are inserting a tracheal tube for anaesthesia, you will be less likely to have an unpleasant surprise during intubation if you make a practice of specifically assessing the patient beforehand for features likely to hinder intubation. For example, check whether the patient has a receding jaw, awkward teeth, a restricted mouth opening, a stiff neck, or swellings in the neck. If you decide that intubation will be difficult, and anaesthesia is necessary, use an inhalational induction and intubation technique. Although slower than an intravenous technique, it is much safer. The worst problems are always the ones you have not anticipated.

If you have just had one unsuccessful attempt at intubation, proceed as follows. First make sure that the patient is oxygenated by inflating the lungs with the bag/bellows and face mask. If you cannot do this, there must be:

- an obstruction in the airway
- laryngeal spasm, or
- a leak around the face mask.

If you cannot rapidly correct the problem, you must oxygenate the patient quickly by another method. Insert a large (14-gauge or, better, 12-gauge) needle through the cricothyroid membrane (see Fig. 10.1, p. 89) into the trachea and

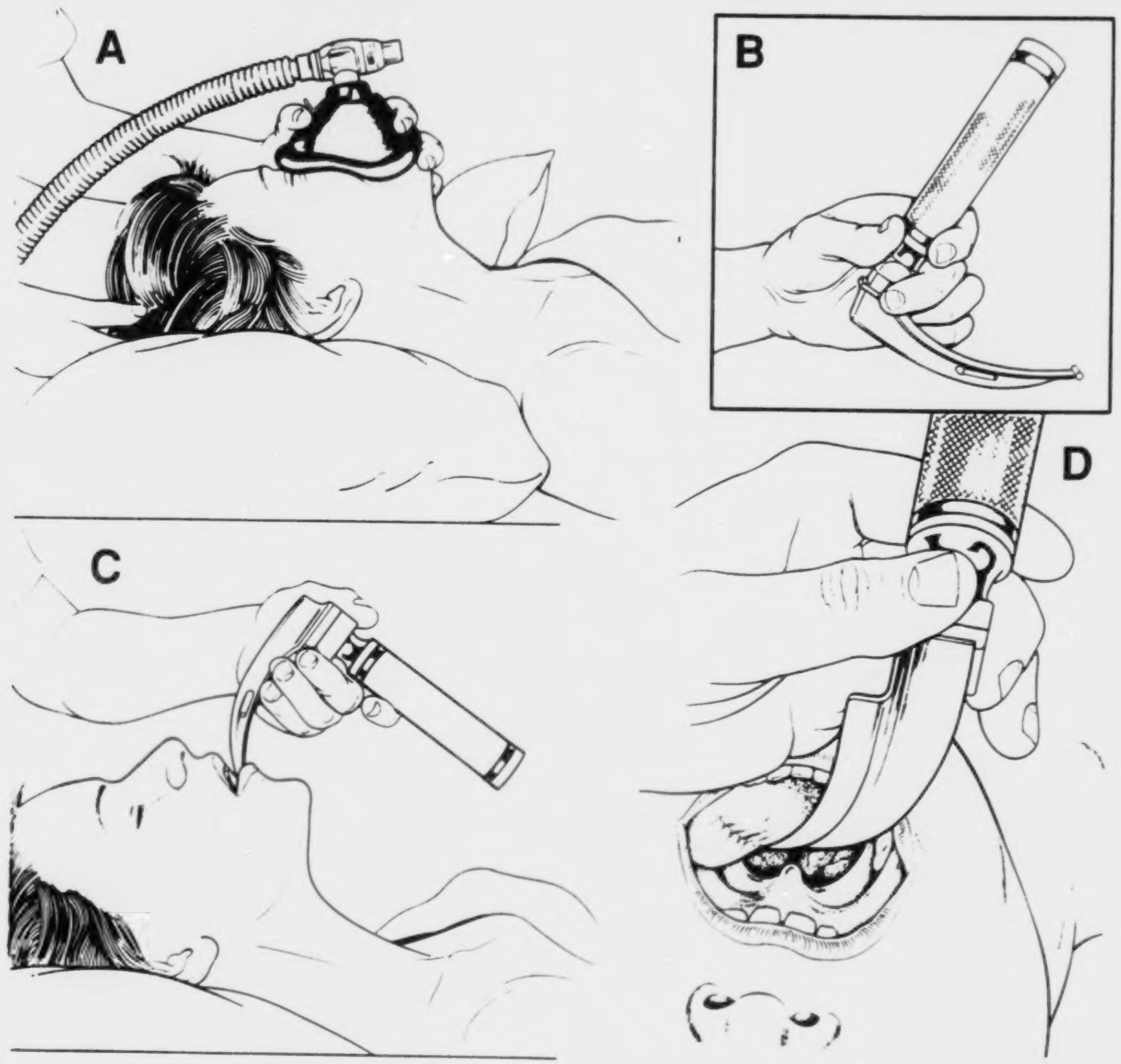

Fig. 2.7. Technique of tracheal intubation. (A) Inflate the lungs with oxygen. (B) Take the laryngoscope with your left hand. (C, E) Insert the laryngoscope blade gently in the right side of the mouth. (D) Initial view of the oropharynx. (F) Insert the blade between the epiglottis and

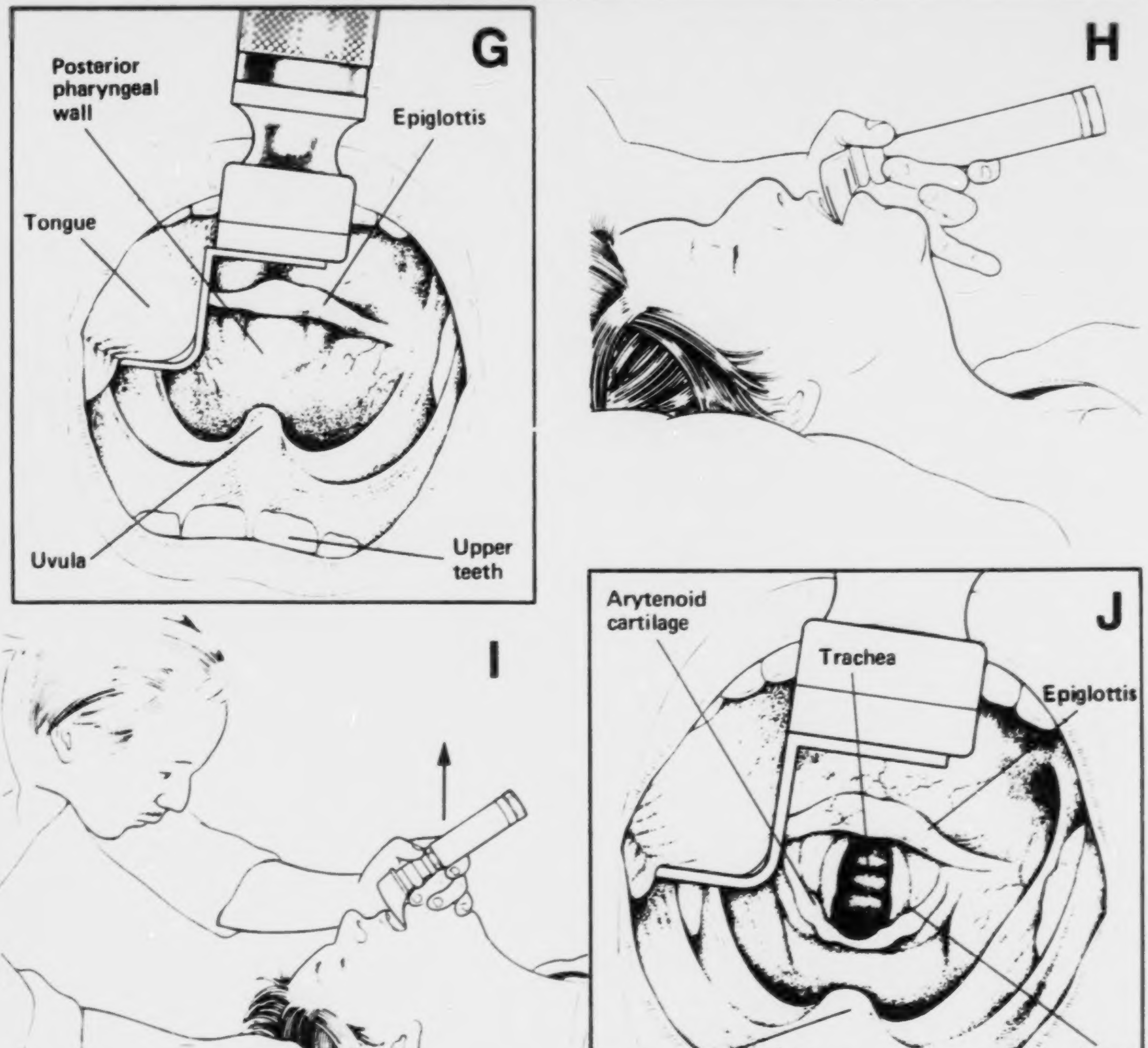
G
Posterior pharyngeal wall
Epiglottis
Tongue
Uvula
Upper teeth
H
I
J
Arytenoid cartilage
Trachea
Epiglottis
Uvula
Vocal cord
K
L

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Fig. 2.7. Technique of tracheal intubation *(continued)*. (G) View of the pharynx and epiglottis. (H, I) Lift the blade towards the ceiling. (J) View of the larynx. (K) Retract the lip to improve the view. (L) Insert the tracheal tube.

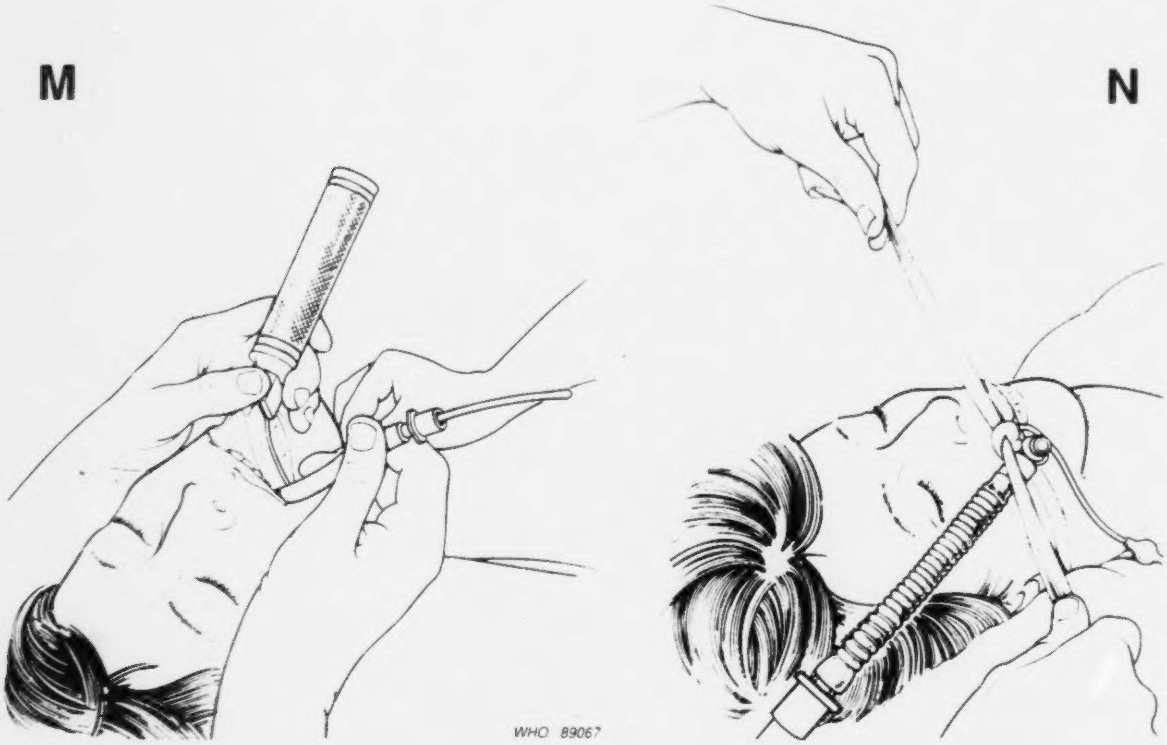


Fig. 2.7. **Technique of tracheal intubation *(continued)*. (M) Use a bougie to help direct the tube while your assistant applies cricoid pressure, if necessary. (N) Securely fix the tube in place.**

connect it to an oxygen supply at 4 litres/min. (Use a 2-ml plastic syringe barrel to make a connector; attach the Luer tip to the cannula and the wide end to the oxygen tubing.) Delivering oxygen in this way will keep the patient alive for a few minutes, while you quickly consider whether the patency of the airway can be restored by:

- changing the position of the patient
- inserting an artificial airway — oropharyngeal, nasopharyngeal, or laryngeal mask
- allowing the patient to wake up, or
- performing an emergency tracheostomy.

(If you have given suxamethonium its effects should wear off within a few minutes, allowing the patient to breathe.)

If you can ventilate the lungs with a face mask, the patient's condition is much more stable. Give the patient at least 10 good breaths of oxygen, and at the same time look again at the position of the head and neck. The head should be extended and the neck slightly flexed (Fig. 2.1, p. 4).

The commonest causes of failed intubation are:

- overextension of the neck, which pulls the larynx away from the mouth
- putting the laryngoscope blade in too fast and too far (without identifying the uvula and epiglottis) and passing the laryngeal opening without seeing it.

Having repositioned the head, if necessary, and ensured oxygenation, you may make (only) one more attempt at intubation, following the steps shown in Fig. 2.7 (pp. 11–13). Put the laryngoscope blade in slowly (you may need to suck out

Table 1. Ten tests of tracheal intubation

Test	Result	Significance	Reliability
Look with laryngoscope	Tube between cords	Correct tracheal intubation	Certain
Listen/feel	Breathing through tube	Correct tracheal intubation	Probable
Tap sternum	Air comes out through tracheal tube	Correct tracheal intubation	Probable
Inflate with SIB	Chest rises and falls	Correct tracheal intubation	Probable
Inflate with SIB	Gurgling noise	Oesophageal intubation	Probable (**remove tube**)
Pass catheter down inside tube	Patient coughs (if not paralysed)	Correct tracheal intubation	Probable
Look	Patient remains pink after intubation	Correct tracheal intubation	Probable
Look	Patient becomes cyanosed after intubation	Oesophageal intubation	Certain (**remove tube**)
Listen with stethoscope	Air entry at both apices, both axillae, and both bases	Correct tracheal intubation	Probable
Listen with stethoscope	Air entry over stomach	Oesophageal intubation	Probable (**remove tube**)

secretions) and find the uvula and epiglottis. If you can identify the two arytenoid cartilages, which lie at the back of the larynx, pass the tube between and in front of them. If you cannot identify the arytenoid cartilages, ask your assistant to press gently on the thyroid cartilage and to retract the patient's upper lip to improve your view, and then insert the tube. It is helpful to use a gum-elastic bougie as a stylet over which the tube can be guided.

Check again whether the tube is in the trachea. If you are not sure, you must remove the tube.

Failed intubation drill

If you have not succeeded in intubating the patient, do not continue with further fruitless attempts. You must keep the airway clear by another means. If anaesthesia is necessary, adopt the *failed intubation drill* as follows.

- Allow the patient to breathe, with an airway inserted if this is of help, and give an inhalational anaesthetic with a face mask. If profound relaxation is required, use 6–10% ether preceded by halothane for a few minutes, if available, to settle the patient. As soon as possible, turn the patient into the lateral position with 10–15 degrees of head-down tilt; it may even be possible to do the operation in this position.
- If the patient has a full stomach, your assistant must maintain cricoid pressure (see p. 77) throughout the operation.
- At the end of the procedure when the patient has recovered, try to determine the specific cause of the difficulty in intubation, so that you can avoid it in the future.
- In cases of failed intubation where the patient's stomach is known to be empty, a laryngeal mask can be inserted to secure the airway.

Care of the patient whose breathing is inadequate

Once you are sure that the airway is clear, check that the patient is breathing adequately. The signs of inadequate or absent breathing are:

- central cyanosis
- no breath heard or felt at the mouth or nose
- no activity of the respiratory muscles.

If these signs are present you must ventilate the lungs immediately by using one of the following techniques.

Ventilation with expired air without intubation

Your own expired air contains 16% oxygen, which is enough to maintain adequate oxygenation in a patient who is not breathing. If you have no ventilating apparatus nearby, start with mouth-to-mouth ventilation (Fig. 2.8): check again that the airway is clear and extend the patient's head; pinch the nostrils, place your mouth over the patient's mouth, and blow into the lungs; watch the chest rise during inspiration; then lift your head and watch the chest wall fall with expiration. When you are ventilating a child's lungs in this way, it is easier to cover both the nose and the mouth with your mouth. Aim for a respiratory rate of 15 breaths per minute in an adult and about 30–40 in a child.

If possible, you should insert an oropharyngeal airway to help keep the airway clear (see p. 5). If an anaesthetic face mask is available, it will make your task easier and more pleasant; use the mask as for an anaesthetic to cover the patient's mouth and nose, and support the jaw at the same time. To inflate the patient's lungs, blow through the hole in the mask. (Brook's double-ended airways are available for the same purpose, but are more difficult to use, and most anaesthetists prefer the face mask.)

Ventilation with an SIB without intubation

Air (or oxygen-enriched air) is drawn into an SIB through a non-return valve, and when the bellows or bag is compressed, the contents are driven into the patient's lungs via a breathing valve and face mask. Some examples of SIBs are shown in Fig. 2.9.

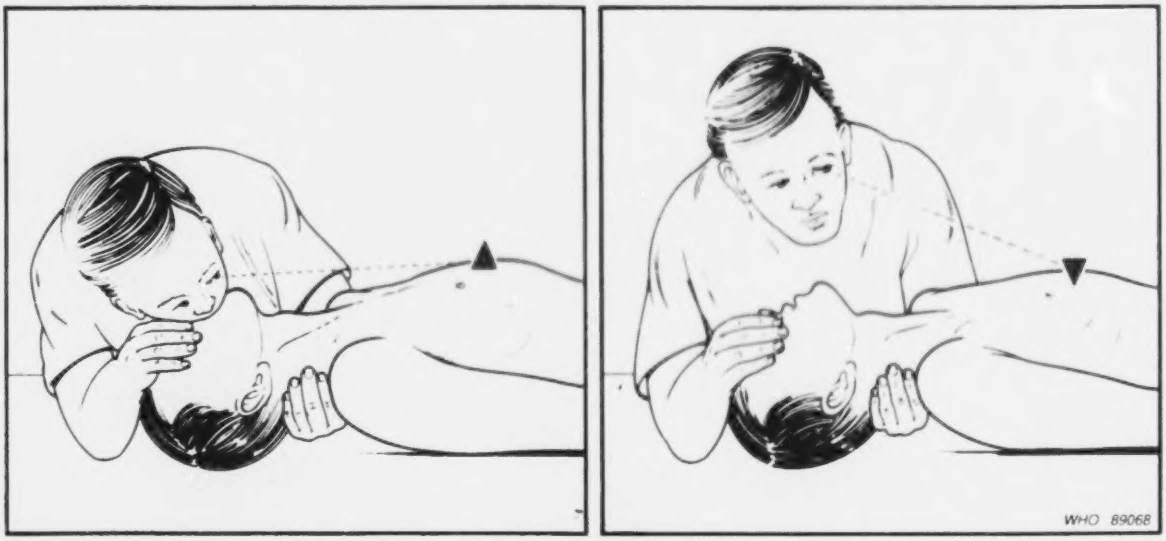


Fig. 2.8. Ventilation with expired air.

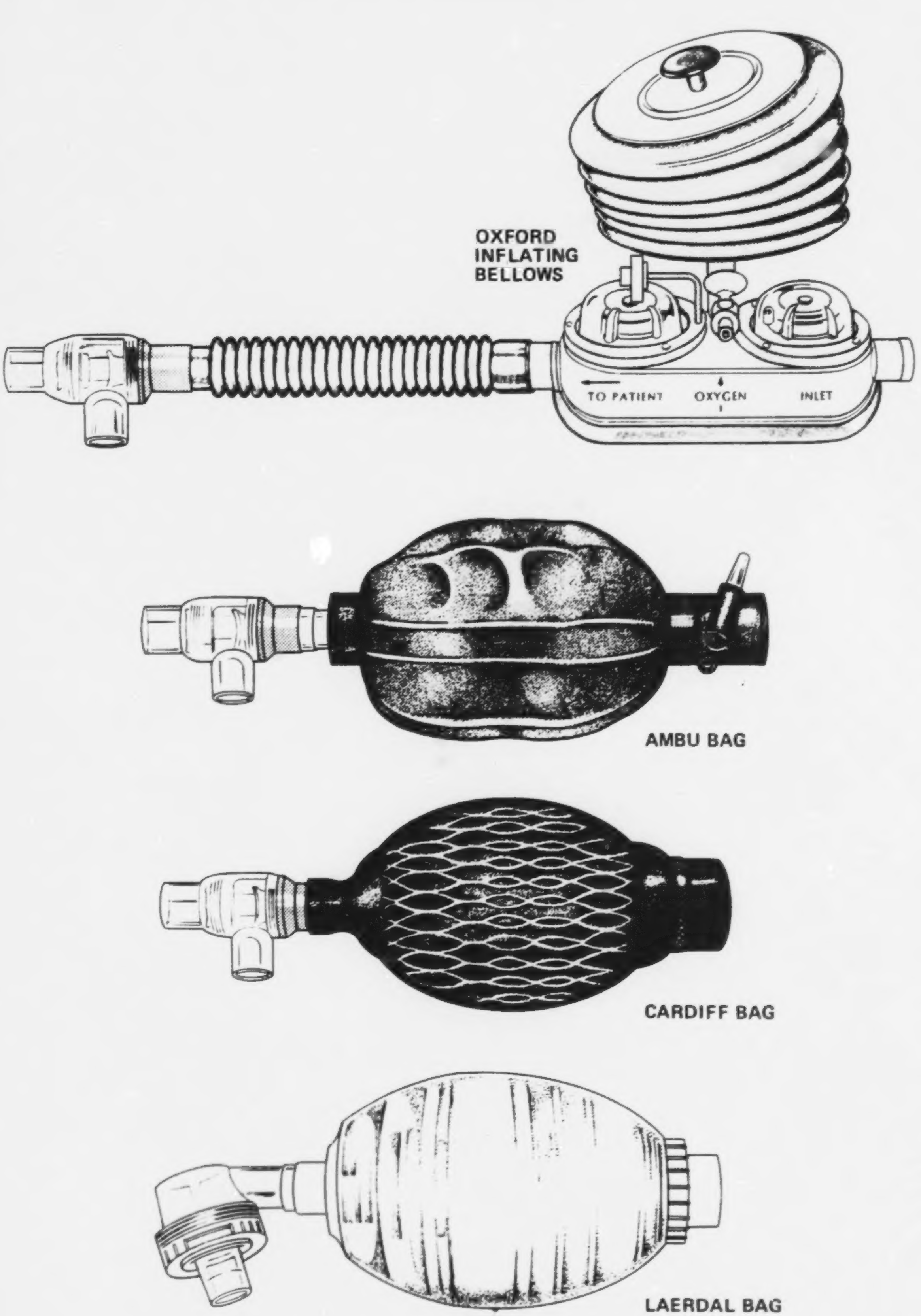

OXFORD INFLATING BELLOWS
TO PATIENT
OXYGEN
INLET
AMBU BAG
CARDIFF BAG
LAERDAL BAG

Fig. 2.9. Apparatus for ventilating the lungs (SIB).

The breathing valve directs air from the SIB into the lungs during inspiration and allows the patient's expired air to pass out into the atmosphere during expiration. The valves shown in Fig. 2.10 are "universal", which means that they can be used for both controlled breathing (intermittent positive pressure ventilation, IPPV) and spontaneous breathing. They are therefore used for both resuscitation and anaesthesia. Check that you have the right sort of valve, if necessary by blowing and breathing through it yourself. The direction of air flow should be as shown in Fig. 2.10.

Connect the SIB via the breathing valve to the face mask. Ensure that the patient has a clear airway and inflate the lungs about 15 times per minute (30–40 times per minute for a child). Allow the patient to breathe out for about twice as long as it takes to inflate the lungs. To ventilate a child's lungs, use a smaller SIB if available or a smaller "squeeze" on an adult-size SIB, or use the mouth-to-mask/tube method.

Oxygen enrichment is always desirable during resuscitation. The simplest and most economical way of providing it is by using a T-piece and reservoir tube at the inlet of the SIB (Fig. 2.11). An alternative can be improvised, if necessary, from any piece of wide-bore tubing with a piece of oxygen tubing running into it. A flow of 1–2 litres/min of oxygen into such a reservoir will increase the oxygen concentration in the inspired gas to 40–50%.

Ventilation with an SIB with intubation

Before intubation you should always inflate the patient's lungs for a few breaths using either a mouth-to-mouth or a face-mask technique; oxygenation always has priority over intubation, which may take several minutes, allowing the patient to become hypoxic. Intubation is desirable if you are giving IPPV with an SIB, since it ensures a stable, clear airway and also provides unique protection against contamination of the lungs with vomit. Remember that, in deeply unconscious patients, no relaxant drugs are needed for laryngoscopy and intubation.

Management of the circulation

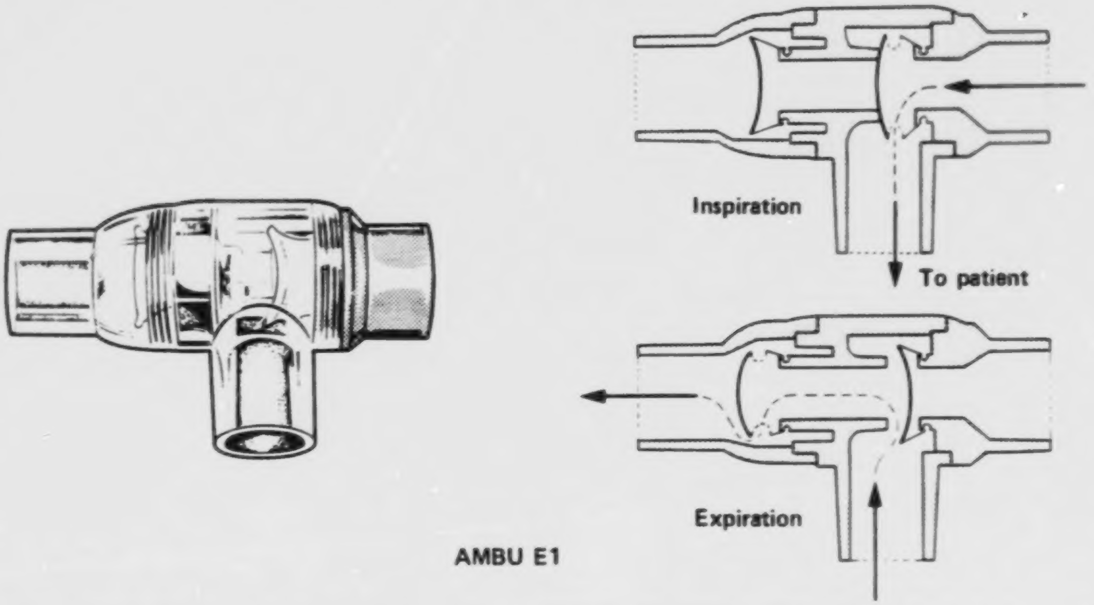
Immediate access to the circulation, i.e. a secure intravenous line, is needed in all critically ill and anaesthetized patients. In the critically ill adult, set up an infusion of an appropriate fluid into a large vein using the largest cannula or needle you have (14-gauge/2 mm is ideal). In some patients, two or more intravenous lines may be needed. If peripheral veins are invisible or inadequate, use large veins in the cubital fossa, the external or internal jugular veins, or even, for short-term use, the femoral vein (but beware of inserting the needle into the artery by mistake). If available, an extra assistant may do a surgical "cut-down" to provide access to the long saphenous vein, but this takes longer.

Control of bleeding

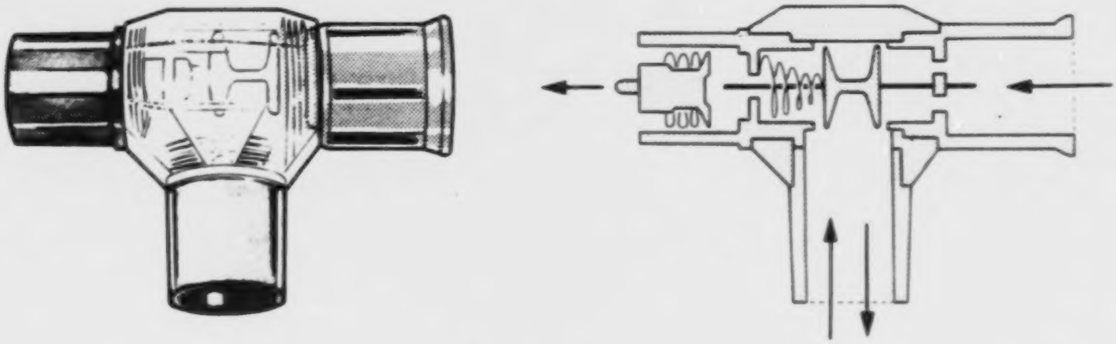
Bleeding from wounds can usually be controlled by firm pressure over a sterile dressing until the patient is ready for surgical exploration and haemostasis. However, some limb wounds, for example a severe crush injury, may need a temporary tourniquet.

Restoration of circulating volume

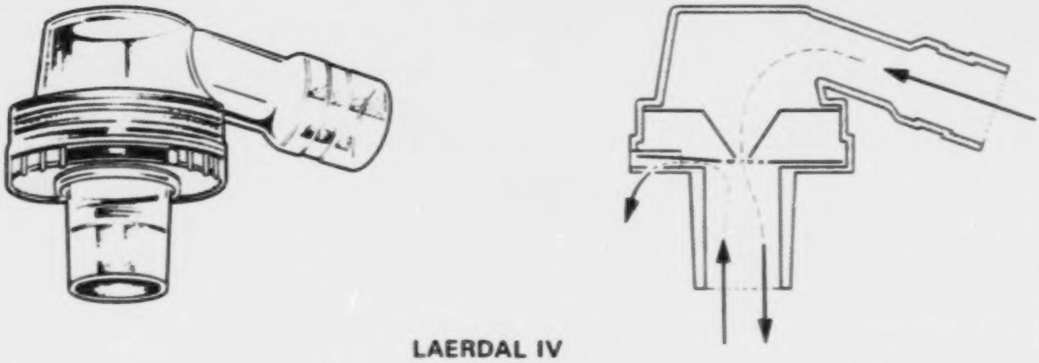
Elevating the legs will often improve venous return in the hypovolaemic patient. Doing this without lowering the trunk and head will avoid the impairment of breathing that is a feature of the head-down (Trendelenburg) position.


Inspiration
To patient
Expiration

AMBU E1



RUBEN



LAERDAL IV

Fig. 2.12. Universal breathing valves.

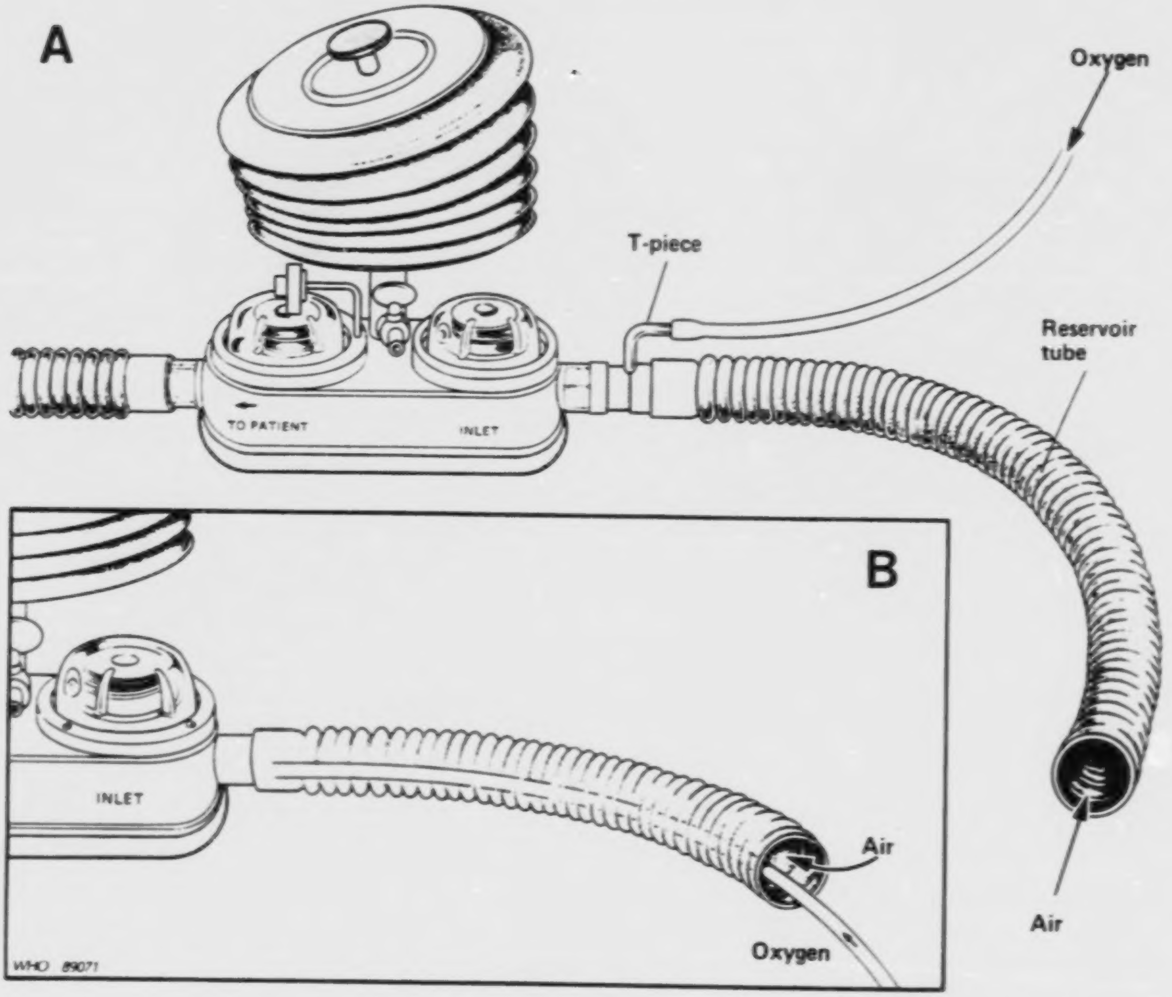


Fig. 2.11. Oxygen enrichment of gas for ventilation with a self-inflating bellows. (A) A T-piece and reservoir tube; (B) an improvised alternative. A similar arrangement can be used at the inlet to a self-inflating bag.

Further restoration of volume can be achieved by the intravenous infusion of fluids. The low blood pressure and cardiac output of hypovolaemia, whether caused by haemorrhage or by dehydration, can rapidly cause severe and irreversible damage to sensitive tissues, such as the kidney and brain, unless circulating volume is rapidly restored. The best fluid to give is one that resembles as closely as possible the fluid lost. It is reasonable to start resuscitation with a solution roughly equivalent to extracellular fluid, for example physiological (normal) saline or Ringer's lactate solution (Hartmann's solution). Metabolic acidosis often complicates severe circulatory failure; if it is severe, sodium bicarbonate may be given intravenously in a dose of 1 mmol/kg of body weight, except to patients with diabetic ketoacidosis in whom bicarbonate can precipitate fatal hypokalaemia.

For the management of unexpected cardiorespiratory arrest, see p. 33.

Assessing the effects of treatment

Failure of the circulation or breathing results in tissue hypoxia and cyanosis (unless the patient is also very anaemic, when cyanosis may not be detectable).

While you are continuing with resuscitation of any unconscious patient, note whether the patient's colour and peripheral perfusion improve. If you are performing external cardiac massage (see p. 34), a femoral pulse should be palpable if the massage is effective. If the patient's colour does not improve quickly, check that you have not forgotten part of the procedure or the assessment. If your resuscitation is effective, the patient will begin to regain consciousness and will start to move, breathe, or respond to stimulation. If the patient starts to breathe, continue to assist breathing until it is regular and adequate, i.e. occurs at a normal rate and depth, and the patient shows no cyanosis. You may then stop artificial ventilation, but continue to give oxygen. If the patient has been intubated, do not remove the tracheal tube. It can be safely left in place until the patient is awake enough to remove it.

Monitor and record the pulse and blood pressure during resuscitation and adjust your treatment accordingly. If the heart rate is under 50 beats/min (100 in a baby) atropine may improve it and increase the cardiac output, and is unlikely to harm the patient. When possible, an electrocardiogram (ECG) should be obtained to provide specific diagnosis of abnormal cardiac rhythms, for which appropriate treatment can be given.

A urinary catheter should be inserted if the patient is hypovolaemic. The production of a urine volume of more than 0.5 ml/kg of body weight per hour is a good indicator that fluid replacement and cardiac output are adequate. Watch also for a rise in the jugular venous pressure, as this indicates that the venous circulation has been adequately filled. A patient who remains anuric (check that the catheter has not been blocked) despite normal blood pressure and jugular venous pressure has developed acute renal failure and must be referred immediately.

Stabilization of the patient

After initial resuscitation of the patient, further assessment and treatment will be needed while resuscitation continues. The treatment may include urgent surgical procedures such as insertion of chest drains, further control of bleeding, wound debridement, immobilization of fractures, and control of pain. Any of these procedures may result in further decompensation of the cardiovascular or respiratory systems, so continued monitoring of vital signs is important. If anaesthesia is necessary, it is vital to restore the patient's circulation to normal before induction. *Above all, the hypovolaemic patient should never be given a spinal anaesthetic, or fatal cardiovascular collapse may follow.*

Transportation of the critically ill patient

After initial resuscitation, the patient will need to be moved to an operating theatre or a ward, or possibly to another hospital for further treatment. Before any such move, the patient's condition must be reasonably stable. The active treatment and monitoring of a patient are more difficult during transportation than in the emergency room, so for any but the shortest journeys you should consider taking additional precautions. If the security of the airway is in any doubt, you should either intubate the trachea or perform an elective tracheostomy. Think again about the need for a chest drain in the traumatized patient, and ensure good immobilization and pain relief for fractures. (Unstable fractures can cause renewed bleeding.) The safest way to give potent analgesics is by intravenous injection of small doses. Do not give analgesics or other depressant drugs to patients with impaired consciousness, or you will make any brain injury worse and possibly fatal. Evaluate the need for a regional anaesthetic block, for example a femoral nerve block for a fractured femur (see p. 97).

You must also decide what equipment should accompany the patient. For any journey of more than a few minutes you will probably need all the resuscitation equipment mentioned so far (laryngoscope, tracheal tube, SIB, intravenous infusion apparatus, etc.) together with supplies of any drugs that may be needed in transit. Most important is the choice of who should accompany the patient, although your choice may be limited. If possible go yourself, or send a nurse or trained assistant familiar with the techniques and apparatus of resuscitation and monitoring.

When to abandon resuscitation

Resuscitation is a very active form of treatment that aims to save the lives of severely ill or injured patients who are capable of subsequent recovery. It may be inappropriate to start this treatment at all in certain patients with progressive and incurable illnesses. It is also pointless to continue resuscitation of a patient for whom, despite your best efforts, there is no hope of recovery. The decision to stop resuscitation is a clinical one, based on examination of the patient. The following points may be useful as a guide.

- A patient who has fixed, dilated pupils *and* stops breathing (but whose airway is not obstructed) after a head injury is unlikely to survive.
- The following signs, if present after 30 min of intensive resuscitation, indicate a poor prognosis:
  - fixed and dilated pupils
  - impalpable femoral and carotid pulses
  - absence of respiration.

If these signs are all present there is no hope of recovery, and resuscitation should be abandoned.

The severely injured patient

When a severely injured patient is admitted to the hospital, it may sometimes be difficult to know where to start. The initial priorities of course are management of the airway, breathing, and circulation. The aim of this section is to give you more specific guidance about the further management of particular injuries.

Injuries of the head and neck

Head injuries vary in severity from minor to fatal, but even what appears to be a minor injury can progress to a fatal one as a result of continued intracranial bleeding. It is therefore important to carefully observe any patient who suffers a head injury sufficiently serious to make them unconscious ("knocked out") even if they were unconscious for only a few seconds. Regular observations of level of consciousness are essential. In patients who are or have been unconscious, use the Glasgow Coma Scale (Table 2) to detect changes in level of consciousness which may signify improvement, or the onset of life-threatening complications requiring immediate action.

The Glasgow Coma Scale is a simple scoring system in which three functions are tested: these are eye-opening, best motor response, and best verbal response. The scores for each of these are added together to give a total score. (Note that the lowest score for each category is 1, not 0.)

The commonest cause of death after severe head injury is an obstructed airway, so make sure that your patient's airway is clear. You must protect the airway of

Table 2. Glasgow Coma Scale[a]

	Response	Score
Eye-opening response (opening of eyes in response to stimulation)	Spontaneous	4
	To speech	3
	To pain	2
	None	1
Best verbal response (response to command or request)	Oriented	5
	Confused	4
	Inappropriate	3
	Incomprehensible sound	2
	None	1
Best motor response (response by voluntary movement of limb to instruction or stimulation)	Obeys commands	6
	Localizes pain	5
	Flexion withdrawal	4
	Abnormal flexion	3
	Extension	2
	None	1

[a] For an objective analysis of the patient's state, add up the score under the three headings. The best prognosis is indicated by a score of 15, the worst by a score of 3. The size and reaction of the pupils indicate the state of intracranial tension and may help to localize the side of injury. Increasing tension first gives a contracted pupil that still reacts to light; later the pupil starts to dilate and loses its light reflex.

an unconscious patient by placing him or her in the semiprone position or by inserting a cuffed tracheal tube. If you suspect an injury of the cervical spine, try to maintain the head and neck in a neutral or slightly extended position, and make sure that enough assistants are present to turn the patient without twisting the neck. Flexion is the manoeuvre most likely to damage the spinal cord after a cervical fracture. If tracheal intubation is necessary in such a patient, for example to allow the surgeon to perform a laparotomy for suspected bleeding, a skilled assistant — the surgeon is best — should hold the head and neck firmly in a safe position while you perform the laryngoscopy and intubation. Do not hesitate to intubate if necessary, especially for anaesthesia. You are much more likely to damage the patient's neck if you try to give an anaesthetic with a face mask, and will also expose the patient to the dangers of regurgitated stomach contents. Avoid nasotracheal intubation, as there may be a basal skull fracture through which you could introduce infection by inserting the tube.

If spinal injuries are suspected and you need to turn the patient, you will need at least four people to "log-roll" him or her, avoiding any twisting of the spine from head to coccyx. A patient who needs to be transported should be put on a firm surface and stabilized in position with pillows or sandbags.

Remember that the patient with a spinal cord injury may develop "spinal shock" because of loss of vasoconstrictor tone and that the blood pressure may be extremely sensitive to changes in position. Give generous fluid therapy if this is so, and insert a urinary catheter.

Bleeding from the scalp can be very severe, so make sure that firm pressure is applied. Radiographs of the skull are unlikely to be helpful in the immediate management of most patients with head injuries. A patient who is totally unresponsive to stimulation and who has fixed and dilated pupils probably has a very severe brain injury, and if such a patient stops breathing (after you have ensured a clear airway by intubation), further resuscitation is pointless. In less severely injured patients a clear airway is vital, since obstructed breathing, hypoxia, and hypercapnia all increase intracranial pressure and thus cause further cerebral damage. Any patient with head injuries and impaired consciousness who needs to be transported must first undergo intubation or tracheostomy.

Chest injuries

Any patient who has fractured ribs can develop a pneumothorax or haemopneumothorax, which requires the emergency insertion of a chest drain. Look for the signs of diminished chest movement and air entry, and a deviated trachea. The physical signs may be difficult to interpret, so you should always obtain a radiograph of the chest as soon as possible. If this confirms pneumothorax or haemopneumothorax, insert a chest drain, connected to an underwater seal, and obtain a second radiograph. Penetrating chest wounds must rapidly be made airtight by a temporary dressing. Any patient with a flail segment — an area of the chest wall that is unstable and moves inward during inspiration — is in severe danger. Give oxygen, and if respiratory distress persists, proceed to tracheal intubation and IPPV before transferring the patient to a larger hospital. (This type of injury may require IPPV for up to 2 weeks.) A patient with a small flail segment who is not in respiratory distress will often do well if given adequate analgesia to alleviate rib pain, which inhibits deep breathing and coughing. For analgesia, consider regular intercostal blocks (see p. 96) with bupivacaine.

Abdominal injuries

There may be intra-abdominal bleeding or rupture of a viscus, without any obvious evidence of external abdominal injury. Intra-abdominal bleeding may be confirmed by peritoneal lavage with saline, but a negative result does not necessarily exclude it, especially if bleeding is retroperitoneal. Always suspect intra-abdominal bleeding in cases of multiple trauma, especially if the visible injuries fail to account for the patient's pulse and blood pressure.

Major fractures

Remember that fractures, whether closed or compound, can be a major source of blood loss: 2–3 litres from a severe pelvic fracture and 1–2 litres from a fractured femur. Immobilize fractures as soon as possible, for example using a Thomas' splint for a fractured femur, and give appropriate fluid replacement and analgesia. Administering small doses of opiates intravenously will often be the safest and most effective analgesic technique. For a fractured femur, a femoral nerve block is simple and safe (see p. 97).

Burn injuries

Burned patients may have hidden injuries from the inhalation of hot or toxic gases. Those with burns of the upper respiratory tract (which may quickly lead to fatal laryngeal oedema) may also have burns of the face and singed nasal hair. Steroids are recommended to control airway oedema, but if they are not rapidly effective, early tracheal intubation or tracheostomy will be required. Oxygen therapy should be given to any patient suspected of having burns of the respiratory tract. Inhalation of smoke or toxic fumes may cause a chemical pneumonitis with severe hypoxia, requiring long-term IPPV. Patients with burns of the respiratory tract should be referred as soon as their condition can be stabilized, which should usually be within 24 hours of injury. Patients with severe pain should be given small intravenous doses of morphine or pethidine until their pain is relieved.

For external burns make an estimate of the percentage area burned. For an adult use the "rule of nines". Each of the following areas can be taken as 9% of the total body area: front of thorax, back of thorax, front of abdomen, back of abdomen, each arm, front of each leg, back of each leg, head plus neck. The area of the perineum is about 1% of the total. For children the area of the head is proportionately much greater, for example 15% for a 5-year-old and 20% for a 1-year-old. Another useful measure is the front of the patient's hand, which usually represents about 1% of the surface area.

Set up an intravenous infusion into a large vein and give fluid replacement as suggested below. Severely burned patients lose blood and protein through the burned surface and must be given colloids and blood as necessary, in addition to the extra saline and water needed to replace excess water losses due to evaporation from burned areas and a very high metabolic rate. Keep the patient in as warm an environment as possible to minimize the metabolic disturbance. Measure hourly urinary output as an index of the adequacy of your fluid therapy and try to maintain a urine flow of at least 0.5 ml/kg of body weight per hour. If you have the apparatus and training to do so, it is helpful to measure central venous pressure, which should be maintained at 10–20 cmH$_2$O (0.98–1.96 kPa) above the right atrium. The erythrocyte volume fraction should be kept if possible in the range 0.30–0.35 (haematocrit 30–35%).

Suggested fluid regimen for burns

When you have assessed the area of the burn, use your estimate to determine the "unit of fluid replacement" from the formula:

1 unit of replacement (in ml) = total area of burns × body weight in kg × 0.5

For example, for a 30% burn in a 60 kg adult the unit of replacement would be 30 × 60 × 0.5 = 900 ml.

Give the replacement fluid as colloid (dextran, polygeline, hydroxyethyl starch, plasma, or blood) according to the following schedule:

1 unit every 4 hours for the first 12 hours
1 unit every 6 hours for the next 12 hours
1 unit during the next 12 hours
(total 6 units of replacement in 36 hours).

In addition, give the daily water requirement of the patient orally, or intravenously as a 5% (50 g/litre) glucose solution (at least 35 ml/kg of body weight per day for adults and 150 ml/kg of body weight per day for children weighing less than 10 kg).

If the sum of the area burned (as a percentage) and the patient's age exceeds 100, the patient is unlikely to survive, but make sure that he or she is comfortable by giving generous doses of opiate analgesics. Patients who survive a severe burn will have a very catabolic metabolism, but will also be anorexic, and will starve to death unless you make a special effort to feed them. This will usually mean the need for nasogastric feeding with a high protein and high calorie diet — up to 25 MJ/day (6000 kcal$_{th}$/day). Repeated anaesthetics may be needed later for painful dressings and skin grafts. Ketamine is a very valuable drug in this situation. Never give suxamethonium to a patient after a severe burn, as it may cause the release of large quantities of potassium ions into the circulation, resulting in cardiac arrest.

3

Care of unconscious and anaesthetized patients

The previous chapter outlined the steps to be taken for the immediate care of critically ill or unconscious patients. This chapter now focuses on the continuing care of unconscious and anaesthetized patients.

A person who is unconscious, whether because of injury or illness or because of the influence of general anaesthetic drugs, lacks many vital and protective reflexes and depends on other people for protection and maintenance of vital functions. It is a doctor's duty to ensure that the patient is protected during this critical period. One person must never act as both anaesthetist and surgeon at the same time; a trained person must always be available specifically to look after the airway, monitor the patient, and care for all vital functions.

General management

Position Patients, whether awake or asleep, must be handled gently at all times. Anaesthesia should always be induced with the patient on a table or trolley that can rapidly be tilted into a steep, head-down position to deal with any sudden onset of hypotension or, should the patient vomit, to allow the vomit to drain out of the mouth instead of into the lungs. General anaesthesia is usually induced with the patient in the supine position, but if you are planning to anaesthetize the patient in the lateral position without a tracheal tube, anaesthesia can be induced with the patient already in that position.

Once anaesthetized, the patient should not be put into abnormal positions that could cause damage to joints or muscles. If the lithotomy position is to be used, two assistants should lift both legs at the same time and place them in the stirrups, to avoid damage to the sacro-iliac joint.

Eyes The eyes should be fully closed during general anaesthesia or the cornea may become dry and ulcerated. If the lids do not close "naturally", a small piece of tape should be used to hold them. They should always be taped in this way if the head is to be draped, and additional protective padding is advisable. If the patient is to be placed in the prone position, special care is also needed to prevent pressure on the eyes, which could permanently damage vision.

Teeth The teeth are at risk from artificial airways and laryngoscopy, especially if they are loose, decayed, or irregularly spaced. Damage from oral airways most often occurs during recovery from anaesthesia, when an increase in muscle tone causes the patient to bite. Laryngoscopy may damage teeth, particularly the upper front incisors, if they are used as a fulcrum on which to lever the laryngoscope. It is safer to remove a loose tooth deliberately, because if dislodged by accident it may be inhaled and result in a lung abscess.

Peripheral nerves

Certain peripheral nerves (for example the ulnar nerve at the elbow) may be damaged by prolonged pressure, and others (for example the brachial plexus) by traction. Careful attention to the patient's position and the use of soft padding over bony prominences can avoid these problems. Tourniquets, if used, must be carefully applied with padding and must never be left inflated for more than 90 min, or ischaemic nerve damage can result.

Breathing

Unrestricted breathing is essential for the unconscious patient. Make sure that the surgeon or assistant is not leaning on the chest wall or upper abdomen. Steep, head-down positions restrict movement of the diaphragm, especially in obese patients, and controlled ventilation may therefore be necessary. If a patient is placed in the prone position, insert pillows under the upper chest and pelvis to allow free movement of the abdominal wall during respiration.

Thermal injury

Protect the anaesthetized patient from being burned accidentally. Beware of inflammable skin-cleaning solutions that can be ignited by surgical diathermy. To prevent diathermy burns, apply the neutral diathermy electrode firmly and evenly to a large area of skin over the back, buttock, or thigh. If other electrical apparatus is in use, beware of the risk of electrocuting or electrically burning the patient.

Heat loss

Keep unconscious patients as warm as possible by covering them and keeping them out of draughts. Most general and regional anaesthetics cause skin vasodilatation, which increases heat loss from the body. Although the skin feels warm, the patient's core temperature may be falling rapidly. Hypothermia during anaesthesia has two harmful effects: it increases and prolongs the effects of certain drugs (for example muscle relaxants) and, by causing the patient to shiver during the recovery period, it increases oxygen demand, which can lead to hypoxia.

Respiratory function in the anaesthetized patient

The principles of keeping a clear airway (described on p. 4) apply as much to the anaesthetized patient as to any unconscious or severely injured patient. Many short or minor surgical procedures, for example incision and drainage, can be carried out with the patient in the lateral or semiprone position, which gives added protection to the airway.

General anaesthesia often impairs the function of the lungs, particularly if the patient is permitted to breathe spontaneously after having been given respiratory depressant drugs, such as morphine or halothane. Very close monitoring of the respiratory system is therefore necessary, though no special or complicated equipment is required. Watch the patient constantly, noting in particular any change in colour or chest movement.

Provided that the patient is not severely anaemic, a healthy pink colour of mucous membranes, fingers, and toes indicates adequate oxygenation. Always make sure that a finger or toe protrudes from under the drapes so that you can observe its colour. Also look at the colour of blood in the surgical wound.

The chest should rise freely with inspiration and fall during expiration. Because the diaphragm descends during inspiration, the epigastric region also rises. If there is an obstruction of the airway, descent of the diaphragm during inspiration causes indrawing of the lower ribs and the tissues at the root of the neck, which is known as "paradoxical respiration".

If respiration is markedly depressed, there may be signs of carbon dioxide retention. Carbon dioxide itself is a depressant, but it causes the release of catecholamines, which produce tachycardia, hypertension, and sweating. They may also cause cardiac dysrhythmias, which can be particularly dangerous if the patient is also hypoxic.

The movement of air as the patient breathes can be monitored by watching the SIB, the breathing valve, or a wisp of thread attached at an appropriate point on the anaesthetic vaporizer (Fig. 3.1). Breathing can also be monitored continuously with a precordial or oesophageal stethoscope. The latter can be easily made by tying a finger from a rubber glove over the end of a stomach tube, passing the tube approximately half way down the oesophagus, and connecting the top end to a normal stethoscope in place of the chest piece (Fig. 3.2). A stethoscope allows the anaesthetist to monitor breath sounds and the respiratory and heart rates; it is simple and reliable and is strongly recommended for routine use. Many anaesthetists find that a monaural earpiece is more comfortable for prolonged monitoring.

During controlled ventilation, as you squeeze the bellows or bag, be alert for changes in resistance that may indicate obstruction or kinking of the tube, accidental disconnection from the patient, the onset of bronchospasm or coughing, or the development of a pneumothorax.

Mechanisms of respiratory obstruction

Obstruction of the upper airways during unconsciousness usually occurs because of loss of muscle tone and reflexes. Obstruction is more likely if the patient has a small lower jaw, a restricted mouth opening, a large tongue, an abnormality in

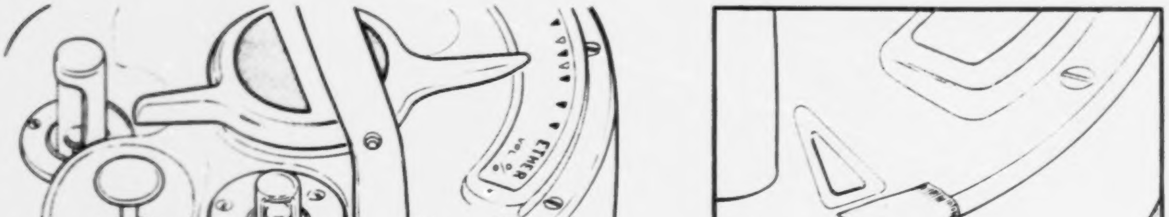


Fig. 3.1. A wisp of thread used as a simple monitor of respiration on a vaporizer.

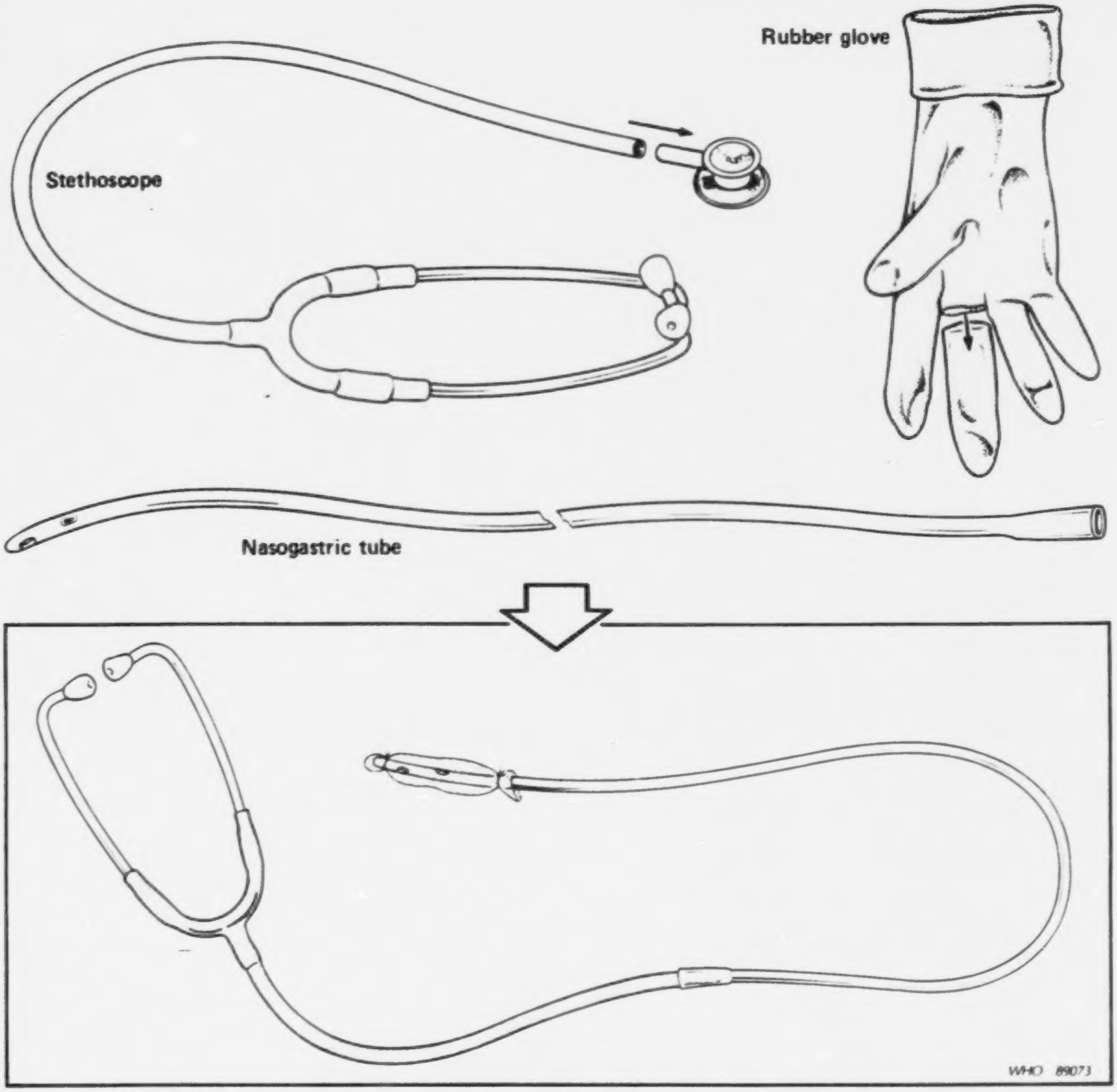


Fig. 3.2. Making an oesophageal stethoscope.

the neck such as a large thyroid swelling, or an abnormal rigidity of the cervical spine. These abnormalities often lead to the tongue falling or being pressed back on to the posterior pharyngeal wall and blocking the passage of air. If this happens suddenly, for example after a bolus of drug has been injected intravenously to induce anaesthesia, and you can neither correct the problem nor ventilate the lungs with a face mask, the patient may die. This sort of sudden obstruction does not occur with inhalational induction of anaesthesia, which is more gradual than the intravenous method. Inhalational induction (see p. 54) is therefore the only safe technique to use in a patient whose airway is difficult to manage.

If the trachea is not intubated, the airway may also become obstructed as a result of laryngeal spasm, which can produce a "crowing" sound (stridor), especially on inspiration. There is a reflex increase in the force of contraction of the inspiratory muscles, resulting in indrawing of the tissues at the root of the neck and paradoxical movement of the ribs, i.e. inwards during inspiration. In patients with severe laryngeal spasm these signs are accentuated, but there is no sound since no air is moving through the larynx. Laryngeal spasm is usually a reflex response to stimulation during light anaesthesia. Either local stimulation (for example laryngoscopy with the patient too lightly anaesthetized) or painful surgical stimulation (for example forcible dilatation of the anal sphincter or cervix) may be responsible. If your patient develops laryngeal spasm, first remove any precipitating stimulus. After a few breaths, the spasm will usually become less marked; you can then deepen anaesthesia so that it will not recur when stimulation starts again. For severe spasm, give suxamethonium intravenously and insert a tracheal tube. Probably the commonest cause of laryngeal spasm associated with anaesthesia is the removal of the tracheal tube with the patient too lightly anaesthetized. To prevent the development of spasm at the end of anaesthesia, you should remove the tracheal tube with the patient either deeply anaesthetized or fully awake.

Even after insertion of a tracheal tube, obstruction may occur as a result of:

- a foreign body or dried mucus in the tube
- thick secretions in the patient's trachea
- kinking of the tube in the mouth or pharynx
- compression of the tube by a surgical gag
- pressure of the tube bevel against the tracheal wall
- herniation of the cuff over the end of the tube
- intubation of a bronchus (which is not really obstruction, but nevertheless causes high inflation pressure and cyanosis).

If, after intubation, your patient's airway appears to be obstructed, you must rapidly check for these possibilities and make appropriate corrections. In particular, check the patency of the tube by passing a suction catheter through it, check the position of the tube with a laryngoscope, and deflate the cuff in case it has herniated over the end of the tube.

If, after you have checked all these points, the patient's airway remains obstructed, you must remove the tube and begin again.

You can prevent certain types of obstruction by taking precautions when inserting the tracheal tube. For example, if you use a stylet in the tube during intubation, you will insure against the presence of foreign bodies. It may also be helpful to cut a hole in the end of the tracheal tube to facilitate air flow should the tube be badly positioned (Fig. 3.3 & 3.4).

Why is airway obstruction so dangerous?

Airway obstruction, if severe, always results in hypoxia, which damages all tissues, but is especially harmful to the heart, brain, and kidney. Minor degrees of hypoxia may be masked if the patient is receiving extra oxygen, but this does not prevent the accumulation of carbon dioxide in the tissues, with associated respiratory acidosis, hypertension, tachycardia, and cardiac dysrhythmias. In addition, the patient who is straining to overcome airway obstruction may generate a large pressure gradient between the thorax and abdomen, resulting in regurgitation of gastric contents into the oesophagus and lungs, with disastrous results.

Respiratory insufficiency

All drugs that depress the central nervous system (for example sedatives, analgesics, inhalational and intravenous anaesthetic agents) are liable to produce some respiratory depression in the spontaneously breathing patient. The depressed respiratory centre fails to stimulate respiration in spite of an adequate

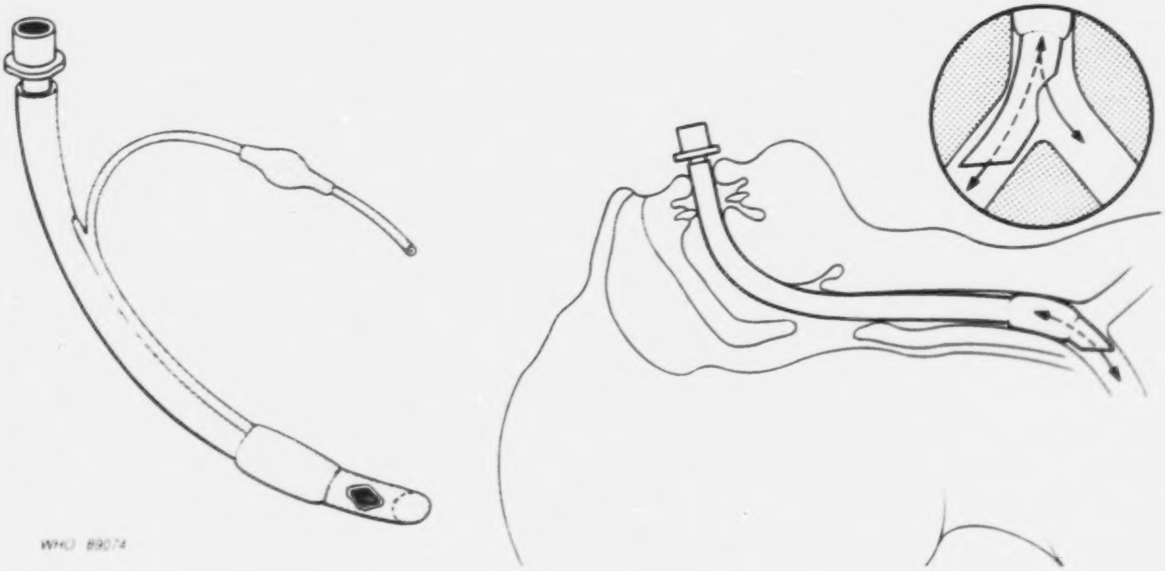


Fig. 3.3. Accidental intubation of a bronchus with a Magill's tube. The danger is less if a hole is cut in the side of the tube below the cuff.

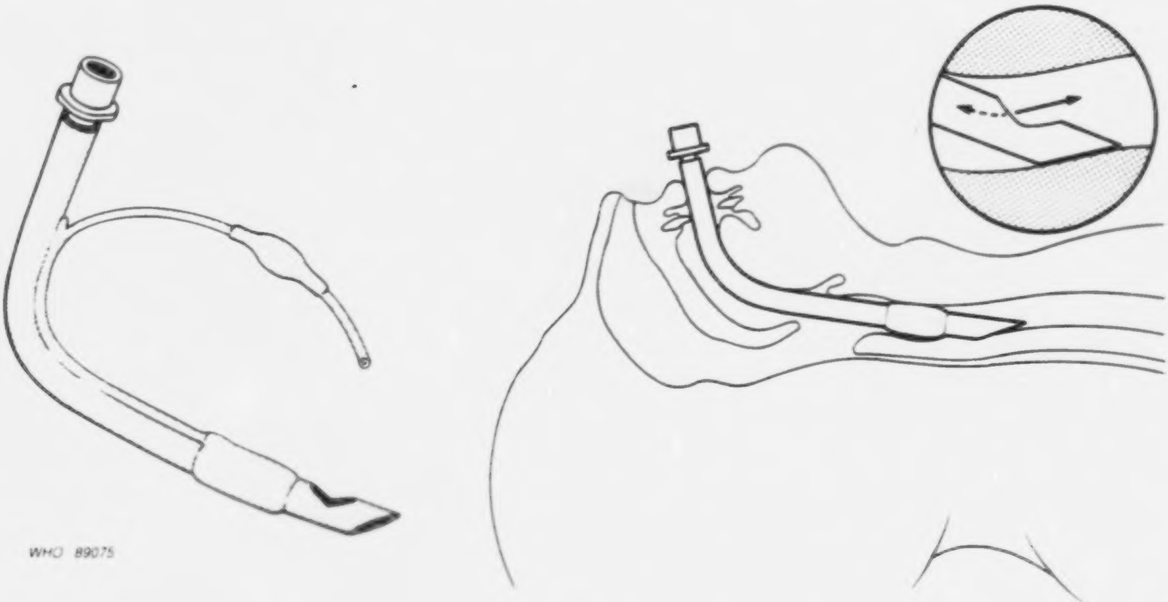


Fig. 3.4. Obstruction of the bevel of an Oxford tube can be prevented by cutting a hole in the lower part of the tube.

stimulus (usually a rising arterial level of carbon dioxide), and the result is a variable degree of hypoxia, hypercapnia, and respiratory acidosis.

Certain factors make patients particularly susceptible to respiratory insufficiency. For example, severe brain injuries, such as those caused by trauma or the hypoxia of a cardiac arrest, depress respiration and may even stop it. Patients with severe chronic obstruction of the airway (such as chronic bronchitis or asthma) also have abnormal respiratory responses and may be extremely sensitive to depressant drugs. In addition, patients who have received muscle relaxants are prone to respiratory insufficiency in the postoperative period if the effects of the relaxant have not been fully reversed at the end of anaesthesia. Certain drugs, if given in large doses during an operation (for example streptomycin at more than 20 mg/kg of body weight), potentiate the actions of muscle relaxants and may therefore accentuate respiratory depression.

In all cases of severe respiratory insufficiency, first give immediate artificial ventilation using a face mask or tracheal tube to restore normal gas exchange. Drug-induced respiratory depression will eventually wear off if IPPV is continued for long enough. For patients suffering from opiate overdosage, use the specific antagonist naloxone, or nalorphine if available. Either of these drugs will reverse opiate-induced respiratory depression, though the effect may wear off before that of the depressant drug, so they must be used with care. Paralysis from muscle relaxants that persists after a normal dose of neostigmine may improve after a second dose of 0.04 mg/kg of body weight (see p. 84). If respiration is still inadequate, continue IPPV until the paralysis wears off and do not give further doses of neostigmine. Persistent or recurrent paralysis is a particular problem in patients who become hypothermic during anaesthesia, since as they begin to warm up during the recovery period, the relaxant remaining in the body becomes more active, and produces so-called "re-curarization". Failure to breathe even after neostigmine has been given to reverse relaxant effects may also result from acidosis, hypokalaemia, and several fairly rare neurological conditions.

The cardiovascular system

It is vital at all stages of anaesthesia or unconsciousness to be aware of the condition of the patient's cardiovascular system. Blood flow through the tissues is of greatest importance, but in practice this can be estimated only indirectly from the patient's heart rate, blood pressure, peripheral colour and temperature, venous filling, and electrocardiogram. Observations and measurements should be made throughout anaesthesia and recorded on a chart similar to the one shown in Annex 3. An accurate record of fluid and blood loss and fluid intake should also be kept. If you detect abnormalities you must inform the surgeon, who may need to take corrective action.

Heart rate

The heart rate can be simply counted by placing a finger over a suitable artery (during anaesthesia it is often easier to use the facial, superficial temporal, or carotid artery than the radial artery) or by listening with a precordial or oesophageal stethoscope. You should record the heart rate every 10 min if the patient's condition is stable, and more often if it is unstable. Tachycardia is usually an indication of increasing activity of the sympathetic nervous system and may indicate hypovolaemia due to excessive fluid or blood loss. Alternatively, it may mean that the patient is becoming too lightly anaesthetized and requires a further dose of anaesthetic drug; in this case the tachycardia is often accompanied by an increase in blood pressure. Bradycardia is usually a reflex response mediated through the vagus nerve; it may occur as a response to visceral stimulation such as traction on the mesentery or dilatation of the cervix. In small children and neonates, bradycardia may indicate hypoxia, which demands immediate correction (see p. 115).

The heart rate is best monitored continuously. The simplest way to do this is with a stethoscope, but in some hospitals a simple, battery-operated pulse monitor may be available. The latter detects pulsatile blood flow in a finger or ear lobe and may display a flashing light with each pulsation, as well as a reading of the heart rate on a dial or display.

Pulse oximetry

A pulse oximeter is a device that is able to detect and display both the heart rate and the degree of saturation of haemoglobin (erythrocyte volume fraction (haematocrit)) by shining a light through a finger or ear lobe. Although these monitors are not cheap, they are beginning to find use in district hospitals, and are a very valuable way of monitoring the patient's cardiovascular system. As with other monitors, they are not, however, a substitute for good clinical observation.

Blood pressure

Blood pressure is most conveniently measured using a cuff, which should be of the right size for the patient. (The width should be between a third and half the distance from elbow to shoulder.) Systolic pressure can be detected by palpation of the brachial or radial artery or by auscultation. In anaesthetic practice, the systolic pressure has greater significance than the diastolic pressure, which is frequently not recorded, particularly if access to the arm is difficult. No "normal" blood pressure can be specified for the anaesthetized patient; in general the systolic pressure should be stable in the range 90–140 mmHg (12.0–18.7 kPa). Measuring the blood pressure of small children may be difficult unless an infant-size cuff is available; a simple technique is to squeeze the forearm firmly, inflate the cuff above systolic pressure, and then note the pressure during deflation at which the forearm flushes with blood. Systolic arterial blood pressure is normally lower in children (45–75 mmHg or 6.0–10.0 kPa in neonates).

Peripheral blood flow

Peripheral blood flow cannot be measured directly, but can be roughly estimated by observing the colour and temperature of the hands and feet. A patient with warm, pink extremities and a normal blood pressure usually has a good cardiac output. You should be aware however that certain anaesthetic drugs, for example halothane, are skin vasodilators, while others, for example ether and ketamine, are not. Remember also that carbon dioxide retention can produce bounding pulses and warm extremities.

A urinary catheter is simple and very useful for assessing cardiac output. Unless the patient is severely dehydrated, as shown by a high relative density (specific gravity) of the urine, the production of urine at a rate of at least 0.5 ml/kg body weight per hour indicates an adequate cardiac output, and it is generally safe to give fluids intravenously until this level of urine production is achieved.

Venous pressure and filling

In a small hospital, measuring the central venous pressure may be difficult, but information can still be obtained by inspecting the patient's neck veins. Position the patient in bed with his or her trunk reclining at an angle of about 45 degrees to the horizontal. Inspect the neck for evidence of venous pulsation. If too large a volume of fluid has been transfused, the patient's neck veins will be filled to a height of more than 15 cm above the sternal angle. In extreme cases, pulsation will not be seen, as the veins will be distended to the top of the neck. In a patient who is not hypovolaemic, the neck veins will be empty in the 45-degree position, but will become filled as the patient is lowered to the supine position. In the severely hypovolaemic patient, the veins will remain empty, even when the patient is supine, and will fill only when the patient is in a head-down position.

The electrocardiogram

Continuous monitoring of the electrical activity of the heart during anaesthesia is not possible unless an electrocardiograph with screen display is available. A paper-writing electrocardiograph may still be of value in the operating theatre to help diagnose dysrhythmias, whose presence is first indicated by abnormalities of the pulse or changes in blood pressure. For patients with evidence of cardiac disease, a preoperative electrocardiogram should of course be recorded.

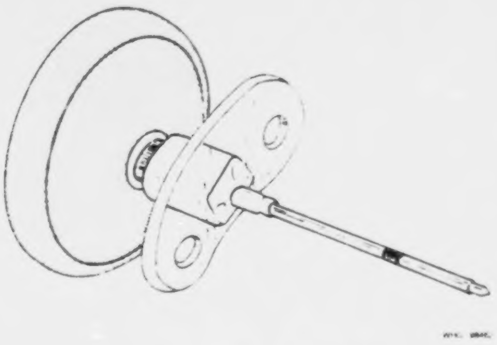


Fig. 3.5. Intra-osseous needle for paediatric resuscitation.

Intravenous access

Before giving a patient any kind of anaesthetic, whether general or regional, you must secure intravenous access with either a plastic intravenous cannula or an indwelling needle. In adults a large forearm vein is ideal for this. Avoid veins where they cross the wrist or elbow joints. In adults the external or internal jugular veins are useful, especially for resuscitation purposes, but use the internal jugular vein only if you have had thorough practical instruction from an experienced teacher. In small children scalp veins are often available. The femoral vein can be used in any patient if you find it difficult to gain access to another vein for resuscitation purposes, but because of greater risks of infection and thrombosis, you should always re-site your infusion within a few hours. (See also p. 17 for intravenous access for emergency procedures.)

For resuscitation of babies and small children the intra-osseous route is becoming popular in some hospitals. This requires the insertion of a special needle (see Fig. 3.5) into the marrow cavity of a long bone, usually the tibia. Insertion of the needle requires special training, since it is important to avoid damaging the growth plate. Fluids and drugs infused through such a needle are rapidly absorbed into the circulation. Because of the risk of infection and osteomyelitis, such a needle must not be left in place for more than 4 hours, so this route is available only for resuscitation.

Management of unexpected cardiorespiratory arrest

If any patient suddenly develops a cardiorespiratory arrest, treatment is extremely urgent; irreversible brain damage will occur if the oxygen supply to the brain is cut off for more than 3 min. It is possible to maintain the circulation and ventilation of the lungs by active resuscitation while the underlying cause of the arrest is treated, and many patients recover well after such treatment. If you are inexperienced, the main problem may well be in deciding whether to start resuscitation. Remember that a patient who has a cardiac arrest cannot survive unless treated, so do not delay. When faced with a collapsed patient, first check the *airway*, *breathing*, and *circulation* (this takes about 15 s). If you diagnose a cardiac arrest, follow the drill below:

Cardiac arrest drill

1. Start resuscitation. Don't leave the patient. Shout "Help — cardiac arrest" until help arrives.
2. Clear the airway and inflate the lungs with whatever means is available: your own expired air or a bag or bellows; always use added oxygen if possible.
3. If there is no major pulse, start external cardiac massage. With one hand on top of the other, press sharply down on the lower third of the sternum in

the midline (Fig. 3.6); this compresses and empties the heart between the sternum and vertebral column. Do not massage the left chest, as this does not compress the heart effectively and is more likely to break the ribs. A massage rate of 60 per minute for adults and up to 120 per minute for small children is appropriate.

4. If you are alone, give 15 chest compressions followed by two breaths; watch the chest rise and fall with each inflation. Repeat this sequence of 15 compressions and two breaths so that the adult patient receives 60 compressions and eight breaths per minute. If a second person is available, one of you should perform five chest compressions; the other then gives one breath. Repeat the sequence so that the adult patient receives 60 compressions and eight breaths per minute. If an SIB and oxygen are available use them.
5. As soon as possible insert a tracheal tube, but do not interrupt cardiac massage and ventilation for more than 20 s to do this.
6. When you can, have a look at the size of the patient's pupils. Small pupils indicate effective resuscitation; fixed, dilated pupils may indicate brain damage from hypoxia. If the pupils are initially large, but then become smaller, your efforts are succeeding.
7. When help is available, set up an intravenous infusion while maintaining ventilation and massage, and give sodium bicarbonate in a dose of 1 mmol/kg of body weight (an 8.4% sodium bicarbonate solution contains 1 mmol/ml).
8. Confirm that the cardiac rhythm has been re-established, by obtaining an electrocardiogram, and treat any dysrhythmias.

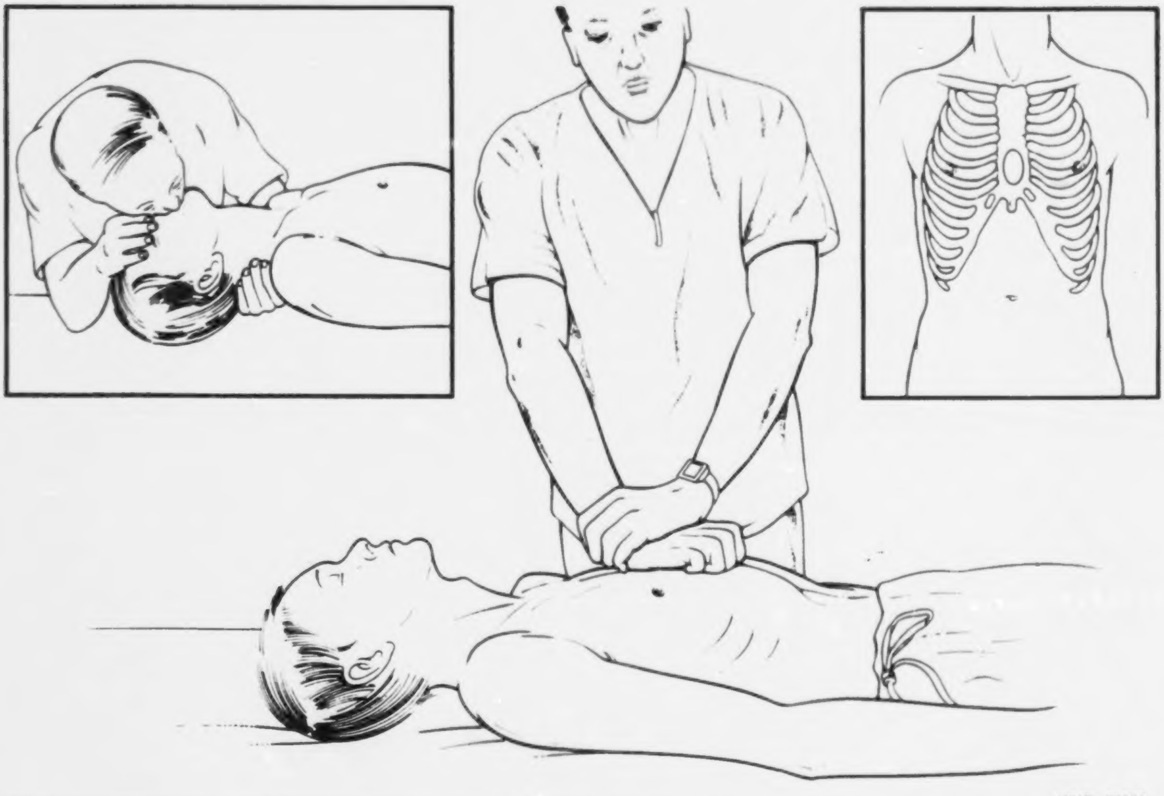


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Fig. 3.6. Expired-air resuscitation and external cardiac massage. The oval marked on the sternum in the drawing on the right shows where pressure should be applied.

9. Investigate the cause of the patient's cardiac arrest and try to determine why it happened when it did. Consider possibilities such as:
   - hypoxia
   - drug overdose
   - allergic reaction
   - myocardial infarction
   - pulmonary embolism
   - disturbance of electrolytes (especially potassium)
   - hypovolaemia.

   Treat the underlying cause of the arrest once you have identified it.

10. Consider using the following drugs in immediate management (doses given are for adults):
    - *Epinephrine (adrenaline)* improves blood flow to the brain during resuscitation, may restore cardiac activity in asystole, and makes electrical defibrillation more likely to succeed in cases of ventricular fibrillation. Dose: 1 mg intravenously (if intravenous access is unavailable, dilute 2 mg in 10 ml saline and squirt down the tracheal tube); 0.5 mg subcutaneously for allergic reactions.
    - *Potassium chloride*, up to 0.3 mmol/kg of body weight intravenously over not less than 5 min for proven hypokalaemia.
    - *Atropine*, 1 mg intravenously for bradycardia or asystole.
    - *Lidocaine*, bolus of 1 mg/kg of body weight intravenously for ventricular arrhythmias.

If your resuscitation is successful, ensure that the patient continues to receive treatment for the underlying cause of the cardiac arrest. Maintain a safe airway after the patient starts to breathe spontaneously again. Do not remove the tracheal tube until the patient has regained consciousness and protective reflexes.

4

Principles of fluid and electrolyte therapy

The body consists of about 60% water by weight in adults, and up to 75% in neonates. Changes in amount and composition of body fluids, which may occur as a result of bleeding, burns, dehydration, vomiting, diarrhoea, and even preoperative and postoperative starvation, can cause a severe physiological disturbance. If any such disturbance is not adequately corrected before anaesthesia and surgery, the risk to the patient is great.

Fluid compartments of the body

The body fluids can be represented as being divided into an intracellular compartment and an extracellular compartment. The extracellular compartment is further divided into intravascular and interstitial compartments (Fig. 4.1).

The intravascular compartment

Normal blood volume is about 70 ml/kg of body weight in adults and 85–90 ml/kg in neonates. In addition to the cellular components of blood, the intravascular compartment contains proteins and ions, chiefly sodium (138–145 mmol/litre), chloride (97–105 mmol/litre), and bicarbonate ions. Only a small proportion of the body's potassium is present in plasma (3.5–4.5 mmol/litre), but the concentration of potassium ions is of great significance for cardiac and neuromuscular function.

The interstitial compartment

The interstitial compartment is larger than the intravascular compartment; anatomically it corresponds roughly to the interstitial spaces of the body. The total amount of extracellular fluid (intravascular plus interstitial) varies between 20% and 25% of body weight in adults and between 40% and 50% in neonates. Water and electrolytes can pass freely between the blood and the interstitial spaces, which have similar ionic composition, but plasma proteins are not free to pass out of the intravascular space unless there is damage to the capillaries, for example as a result of burns or septic shock. If there is a water deficit in the blood or a rapid fall in blood volume, water and electrolytes pass from the interstitial compartment into the blood to restore the circulating (intravascular) volume, which physiologically has priority.

Intravenously administered fluids that contain mainly sodium and chloride ions, such as physiological (9 g/litre or 0.9%) saline or Hartmann's solution (Ringer's lactate solution), pass freely into the interstitial space and are therefore effective in raising the volume of intravascular fluid only for a short time. Solutions containing much larger molecules, for example albumin, whole blood, dextran, polygeline, and hydroxyethyl starch are more effective in maintaining the circulation when

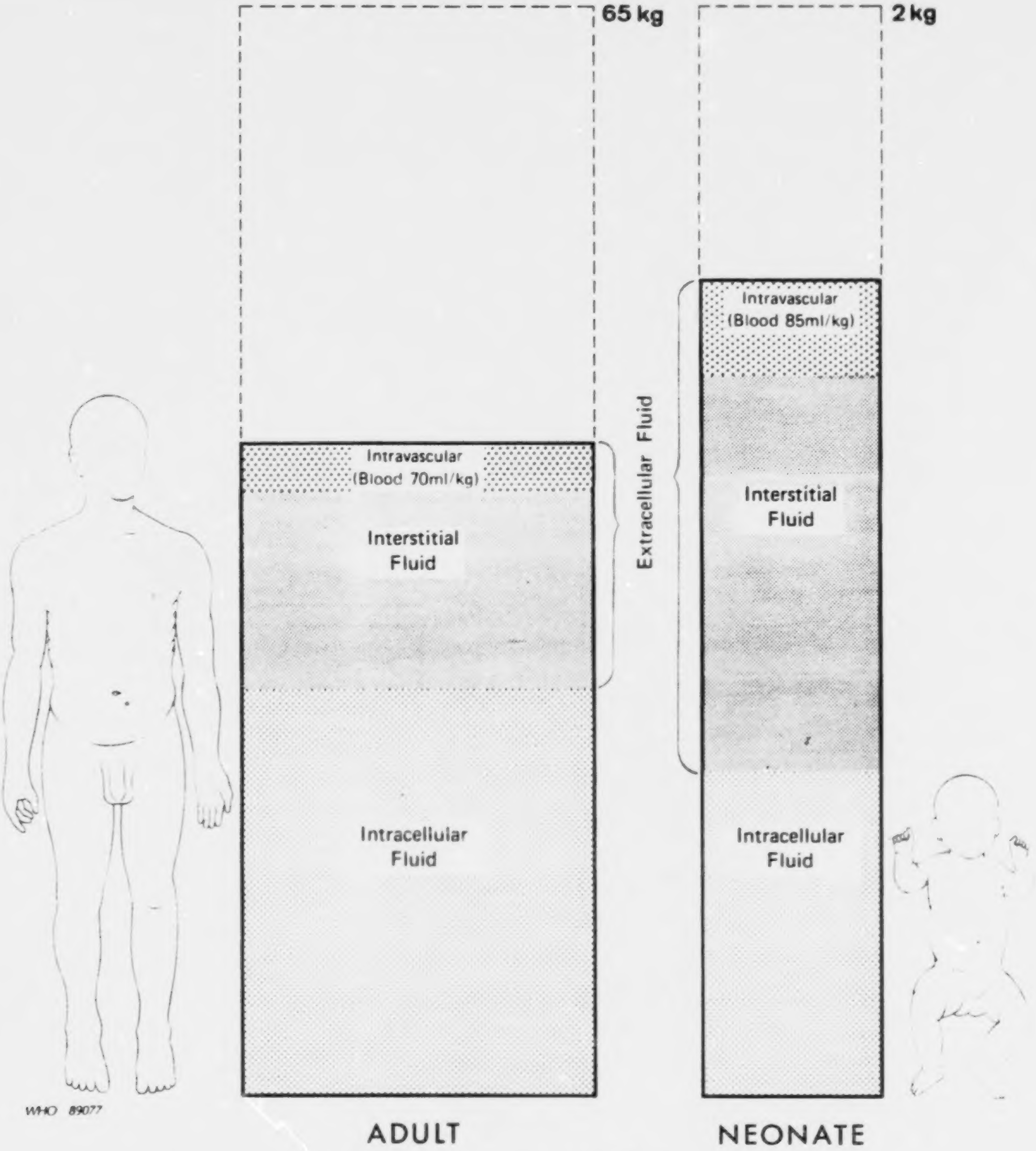
65 kg
2 kg
Intravascular
(Blood 70ml/kg)
Interstitial Fluid
Intracellular Fluid
Extracellular Fluid
Intravascular
(Blood 85ml/kg)
Interstitial Fluid
Intracellular Fluid
WHO 89077
ADULT
NEONATE

Fig. 4.1. Fluid compartments of the body.

given intravenously because they remain in the intravascular compartment for a longer period. These fluids are often referred to as "plasma expanders".

The intracellular compartment

The intracellular compartment is the largest reservoir of body water, and corresponds to water within cells. Its ionic composition differs from that of extracellular fluid chiefly because it contains a high concentration of potassium ions (140–150 mmol/litre) and low concentrations of sodium ions (8–10 mmol/litre) and chloride ions (3 mmol/litre). Thus if water is given with sodium and chloride ions, it tends to remain in the extracellular compartment. Water given as a glucose solution can be distributed throughout all body compartments, the glucose being metabolized. *Pure water must never be given intravenously, since it will immediately cause massive haemolysis.*

Fluid therapy

The most important principle of fluid therapy is that the fluids given should be as close as possible in volume and composition to those lost. Acute losses (such as bleeding) should be replaced promptly; more caution is needed with the replacement of chronic losses, because fast infusions into chronically malnourished and dehydrated patients can cause rapidly fatal heart failure. Chronic fluid losses are better replaced by oral or, in the absence of diarrhoea, rectal rehydration therapy. It is particularly important not to give a sodium overload to a dehydrated patient who is deficient mainly in water.

Fig. 4.2 indicates the many possible ways in which body fluid can be lost and the replacement solutions most likely to be of value for intravenous

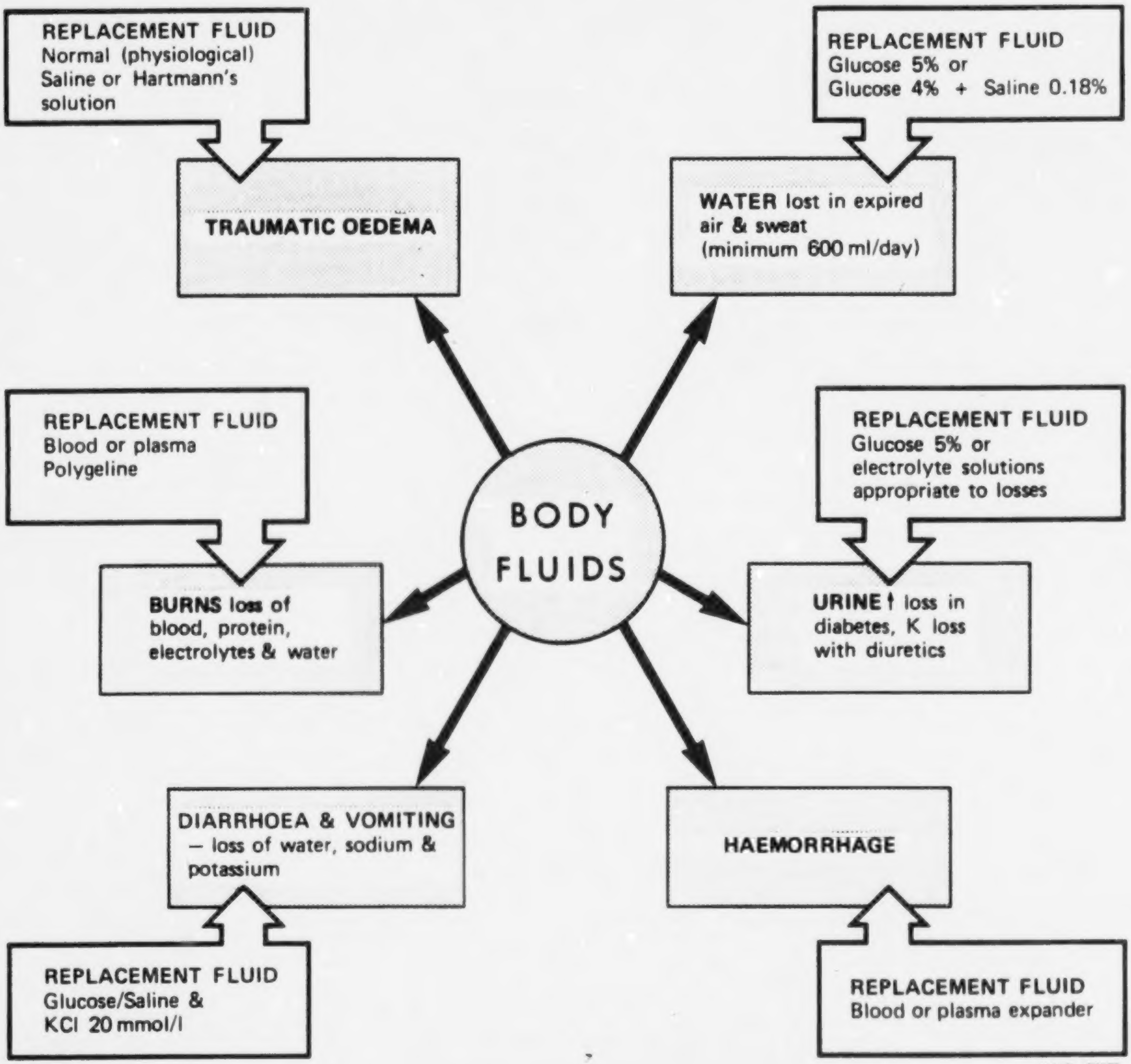
REPLACEMENT FLUID
Normal (physiological) Saline or Hartmann's solution
TRAUMATIC OEDEMA
REPLACEMENT FLUID
Glucose 5% or Glucose 4% + Saline 0.18%
WATER lost in expired air & sweat (minimum 600 ml/day)
REPLACEMENT FLUID
Blood or plasma Polygeline
BURNS loss of blood, protein, electrolytes & water
BODY FLUIDS
REPLACEMENT FLUID
Glucose 5% or electrolyte solutions appropriate to losses
URINE ↑ loss in diabetes, K loss with diuretics
DIARRHOEA & VOMITING – loss of water, sodium & potassium
HAEMORRHAGE
REPLACEMENT FLUID
Glucose/Saline & KCl 20 mmol/l
REPLACEMENT FLUID
Blood or plasma expander

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Fig. 4.2. Fluid losses and some appropriate fluids for intravenous replacement.

Table 3. Commonly available replacement fluids

Fluid	Ions (mmol/litre)			Carbohydrate (g/litre)	Energy content (kJ [$kcal_{th}$])	Uses
	Na^+	Cl^-	K^+			
Blood	140	100	4	5–8	NA	Blood loss
Physiological saline (9 g/litre)	154	154	0	0	0	Blood/extracellular fluid loss
Hartmann's solution (Ringer's lactate solution)	131	112	5	NA	NA	Blood/extracellular fluid loss
Glucose 50 g/litre	0	0	0	50	837 [200]	Dehydration
Glucose/saline (glucose 40 g/litre + sodium chloride 1.8 g/litre)	31	31	0	40	669 [160]	Maintenance of electrolyte and water balance
Sodium bicarbonate 84 g/litre	1000	0	0	0	0	Acute acidosis
Dextran 70 in physiological saline	144	144	0	0	0	Volume replacement
Polygeline	145	150	0	0	669 [160]	Volume replacement

NA = not applicable

therapy. Table 3 shows the main features of commonly available replacement fluids.

Clinical assessment of fluid status

As with all clinical assessments, your task will be much easier if you first obtain an accurate history of the patient's condition, either from the patient or from a relative. This will often help you to decide which fluids have been lost, whether the loss has been acute or chronic, and what form replacement should take.

Loss of water and/or electrolytes

The patient's general appearance may help you assess fluid losses, though up to 10% of body water can be lost without obvious clinical signs. Greater losses cause sunken eyes, loss of tissue turgor, and a dry tongue, though these signs may be masked by oedema from hypoalbuminaemia or obesity. Cool, cyanosed extremities and invisible peripheral veins are further signs of hypovolaemia, and blood pressure may be low with an associated tachycardia. During controlled ventilation, the patient's blood pressure may fall dramatically or the pulse wave may disappear completely with each inspiratory stroke of the bellows. Urinary output may be low, and the relative density (specific gravity) of the urine high.

Laboratory investigations

In dehydrated patients the blood urea concentration will be higher than normal, as will the haemoglobin concentration and the erythrocyte volume fraction, unless the patient was previously anaemic. Initial investigation of the patient should include weighing — a simple and economical way of later assessing how much fluid has been replaced.

A patient with severe depletion must be given fully corrective fluid therapy before anaesthesia. This applies to both general and spinal anaesthesia, as either of these can cause fatal cardiovascular collapse in volume-depleted patients. In extreme conditions, for example torrential obstetric bleeding, where surgery cannot be delayed, local infiltration of anaesthetic can be regarded as the only safe (or as the least unsafe) technique.

Estimation of blood losses during surgery and the need for blood transfusion

In many countries, blood transfusion is associated with specific hazards of disease transmission (hepatitis viruses, human immunodeficiency virus (HIV), syphilis, malaria, etc.), and effective screening of blood for transfusion-transmissible diseases may not be available.[1] The decision to transfuse blood or blood products must be based on a careful assessment of clinical and laboratory indications that a transfusion is necessary to save life or prevent serious morbidity.

Before prescribing blood or blood products for a patient, ask yourself the following questions:

- What improvement in the patient's clinical condition am I aiming to achieve?
- Can I minimize blood loss to reduce this patient's need for transfusion?
- Are there any other treatments I should give before making the decision to transfuse, such as intravenous replacement fluids or oxygen?
- What are the specific clinical or laboratory indications for transfusion for this patient?
- What are the risks of transmitting HIV, hepatitis viruses, or other infectious agents through the blood products that are available for this patient?
- Do the benefits of transfusion outweigh the risks for this particular patient?
- What other options are available if no blood is available in time?
- Will a trained person monitor this patient and respond immediately if any acute transfusion reactions occur?
- Have I recorded my decision and reasons for transfusion on the patient's chart and the blood request form?

Finally, if in doubt, ask yourself the following question:

- If this blood was for myself or my child, would I accept the transfusion in these circumstances?

It is now generally accepted that for relatively healthy patients it is not necessary to maintain the blood haemoglobin concentration at the "normal" adult level (i.e. 120–140 g/litre). When a patient comes for elective surgery and is found to be anaemic, it is reasonable to treat the underlying condition (with oral iron, folic acid, anthelminthics, etc.) for a period of weeks to correct the anaemia and restore the haemoglobin concentration to an adequate level — this is especially important if the operation proposed is a major one, since it may prevent the need for a blood transfusion. In some hospitals patients can pre-donate several units of blood for themselves before surgery — the blood is stored for up to 3 weeks while the patient receives supplements of iron and folic acid. Such patients can receive their own blood at the time of surgery, without risk of disease transmission.

For patients who cannot wait, and who may need a transfusion, the following principles apply.

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[1] See *The clinical use of blood*, Geneva, World Health Organization, in press (unpublished document WHO/BTS/99.2; available on request from Blood Safety and Clinical Technology, World Health Organization, 1211 Geneva 27, Switzerland) and *Safe blood and blood products: distance learning materials*, Geneva, World Health Organization, 1993.

Preoperative level of haemoglobin

There is no predetermined level of haemoglobin below which a patient cannot undergo anaesthesia or surgery. Patients most tolerant of anaemia are those who are chronically anaemic, the young, and those without cardiovascular disease. In general there is no need for transfusion if their haemoglobin level remains above 70 g/litre.

Blood loss

If there is acute blood loss (from trauma or operation) of more than 5–10% of the patient's blood volume, give intravenous fluid replacement. If the blood loss exceeds 25–30% of the blood volume (1000–1500 ml for an average adult), a blood transfusion is likely to be necessary. Because of the potential risks of transfusion, it is vital to make as accurate an assessment as possible of the amount of blood lost, and this will involve regular inspection of the suction jar, weighing swabs (before they dry out), and estimating the amount of blood on the floor and on the surgeon's gown. Expertise at estimating blood loss comes with experience. Take the opportunity to deliberately soak a swab with 20 ml of blood to give yourself a mental picture of this volume of blood. Always use graduated suction jars; a small measuring cylinder can be used for paediatric surgery.

Frequent measurements of the erythrocyte volume fraction (haematocrit) during and at the end of surgery are very useful. Remember that blood loss may not stop at the end of the operation; drains are placed by the surgeon in the expectation that something will come out of them!

If a patient becomes anaemic during surgery, the normal physiological response is to try to increase the amount of oxygen delivered to the tissues by an increase in cardiac output of up to four times the normal resting level — this is achieved by increasing both the quantity of blood pumped by the heart with each beat and the heart rate. This is within the capability of a normal healthy heart, but in patients with heart disease there is a substantial risk of complications if the haemoglobin concentration is allowed to fall below about 90 g/litre — although a lower level may be safe if the patient is known to have been anaemic without symptoms before surgery.

In addition to the blood lost during the operation — from the wound on to swabs, drapes, and the floor, and into the sucker and surgical drains — fluid is lost from the circulation and other extracellular compartments into traumatized tissue as oedema fluid. If the mesentery with an area of 1 m^2 becomes thickened with oedema by 1 mm, the fluid lost from the circulation will be 1 litre. During major surgery, it is standard practice to give clear fluids at a rate of 5 ml/kg of body weight per hour, using Hartmann's solution or physiological saline for adults and glucose 5% (50 g/litre) or glucose 4% (40 g/litre) with saline 0.18% (1.8 g/litre) for small children who do not have the capacity to excrete large quantities of sodium ions.

The anaesthetist is responsible for estimating blood and fluid losses in the operating theatre and for prescribing fluid replacement during and after the operation. It is best to reassess the patient constantly and not to prescribe a fluid regime for more than 6–12 hours at a time, particularly for sick patients and for children.

Autologous transfusion

This simple procedure can be life saving when correctly applied — it is most likely to be used in cases of ruptured ectopic pregnancy, ruptured spleen, or a large haemothorax. It should be used only where blood can be recovered from a cavity where it has lain for less than 24 hours. It must never be used if there is any possibility of contamination with bowel contents (e.g. in cases of severe abdominal trauma), or if there is any evidence of haemolysis. Blood is scooped (not sucked) out of the cavity using a sterile jug or gallipot and filtered through a minimum of 8 layers of sterile gauze into 0.5-litre bottles into which the anticoagulant contents of plastic blood bags used for routine blood donation have been transferred in a sterile manner. A rule of thumb is one bag per bottle: a standard blood bag containing 63 ml of citrate–phosphate–dextrose solution will provide enough anticoagulant for up to 450 ml of whole blood. If blood bags pre-loaded with anticoagulant are not available, for each 0.5-litre bottle, 60 ml of 3.8% sodium citrate (3.8 g/litre) can be used, or 120 ml of acid–citrate–dextrose solution (containing trisodium citrate dihydrate, citric acid monohydrate, and glucose). Gently agitate the bottle during collection. If any clots are seen, repeat the filtration. When the bottle is full it is ready for immediate re-infusion. Do not store it.

Intra-osseous infusion

When a child requires emergency resuscitation it may be possible to give fluids by the intra-osseous route. A special needle is inserted into the upper tibia (in a downward direction pointing away from the epiphysial plate) and fluids suitable for intravenous use are run into the marrow cavity from which they are rapidly absorbed. Once effective resuscitation has been carried out, discontinue the infusion and substitute a conventional intravenous infusion. *Because of the risk of infection (osteomyelitis), intra-osseous infusions must never be used for more than 4 hours, and the sterility of the needle used must be assured.*

Specific losses and replacement

Water

Water depletion occurs most commonly because of inadequate intake (often due to illness itself) in the face of continuing or excessive losses, for example due to sweating, fever, or diarrhoea. The best way to rehydrate such patients is by mouth, using clean water and other drinks. If rehydration by the oral or rectal route is not possible, the best way to give water intravenously is as a 5% glucose (50 g/litre) solution. This solution should not be regarded as a "feeding" solution, as the carbohydrate and caloric content is low (only 837 kJ or 200 kcal_{th} per litre). For patients whose condition is stable and who also require electrolyte therapy, 2–3 litres of glucose/saline solution (4% glucose, 0.18% sodium chloride) provide the average daily requirement of both water and sodium for an adult in a temperate climate.

Diarrhoea and vomiting

Diarrhoea and vomiting usually involve losses of water and of sodium, potassium, and other ions. Replacement is best done orally if possible, using a solution of oral rehydration salts (ORS) or equivalent.

The standard solution of oral rehydration salts (ORS) contains 20 g of glucose (anhydrous), 3.5 g of sodium chloride, 2.9 g of trisodium citrate dihydrate, and 1.5 g of potassium chloride per litre.

Intravenous replacement will require saline, glucose solution (for the water it contains), and potassium. The exact proportions needed can be determined by measuring the patient's plasma electrolyte concentrations and haematological variables. It is important to avoid a sodium overload, particularly in children.

Haemorrhage and burns

The ideal replacement fluid is the one closest in composition to the one lost — blood or plasma. For initial resuscitation of the patient with hypovolaemic shock, the use of saline or Hartmann's solution is common, but you must remember that these may rapidly move out of the circulation into other compartments. Alternatively, a "plasma expander" may be used. These are natural or synthetic substances with a high relative molecular mass (molecular weight) that are retained within the blood vessels and that in turn retain fluid in the vessels because of the osmotic pressure they exert (in the same way as plasma proteins). Examples are the dextrans, polygeline, and hydroxyethyl starch. These substances can be used in cases of severe haemorrhage to reduce the requirement for whole blood, but they cannot of course transport oxygen. For severe haemorrhage, blood transfusion is essential.

Production of sterile fluids for intravenous use

Sterile fluids for intravenous use are relatively costly. Consequently, some hospitals prepare their own supplies, if the quantities they use justify the considerable effort involved. In certain countries, for example the United Republic of Tanzania, a "do-it-yourself" production kit is available. The basic requirements for producing fluids for intravenous use are a clean and reliable water supply, availability of the appropriate chemical salts, pyrogen-free glass bottles and stoppers that can be autoclaved, an efficient autoclave, and trained staff. (Full details of this process are available from ELCT Infusions Unit Project, Box 481, Moshi, United Republic of Tanzania.)

5

Assessing the patient before anaesthesia

Failure to make a proper assessment of the patient's condition is one of the commonest and most easily avoidable causes of mishaps associated with anaesthesia. There is no such thing as a "minor" anaesthetic, and all patients need to be properly assessed before anaesthesia by the person who will administer the anaesthetic. Such an assessment must include every aspect of the patient's condition, and not just the pathological problem requiring surgery.

The initial assessment of a patient includes taking a full medical history (see Fig. 5.1); certain points will be of particular interest to the anaesthetist. The pathological problem requiring surgery and the operation proposed are also of obvious importance, and you will want to know how long the procedure is likely to take. Ask the patient about previous operations and anaesthetics and about any serious medical illnesses in the past, with specific inquiry about malaria, jaundice, haemoglobinopathies, and diseases of the cardiovascular or respiratory systems. In relation to the patient's current health, ask about exercise tolerance, cough, dyspnoea, wheeze, chest pains, dizzy spells, and blackouts. Is the patient taking any regular drug therapy? Drugs of special significance to anaesthesia include antidiabetic drugs, anticoagulants, antibiotics, steroids, and antihypertensive drugs — treatment with the last two should be maintained during anaesthesia and surgery, but other types of drug therapy should be modified as necessary. Note any known allergies on the drug prescription chart (you cannot wake the patient up during the operation to check!) together with any known adverse reactions to anaesthesia experienced in the past by either the patient or the patient's blood-relations. (The dangerous conditions of suxamethonium apnoea and malignant hyperthermia are often familial, so any patient with a family history of such conditions should be referred to a larger hospital. In an emergency it would probably be safe to anaesthetize the patient with ketamine or a local anaesthetic, but suxamethonium is absolutely contraindicated.)

Finally, assess recent fluid losses from bleeding, vomiting, diarrhoea, or other causes and ask about the patient's dietary history. Has he or she been able to eat and drink normally up to the time of admission? If not, you should suspect fluid or nutritional deficiencies and take active steps to correct these before the operation. Find out when the patient last had any food or drink, and explain the need for fasting before anaesthesia.

Examining the patient

Look first for general signs of illness. Is your patient pale, jaundiced, cyanosed, dehydrated, malnourished, oedematous, dyspnoeic, or in pain?

Next take a good look at the patient's upper airway and consider how you are going to manage it during anaesthesia. Will the airway become obstructed easily?

Will it be easy or difficult to intubate? (Most are easy!) Has the patient any loose or awkward teeth, a small lower jaw, or limitation of neck movement, any of which may make laryngoscopy difficult? Are there any abnormal swellings in the neck that could distort the anatomy of the upper airway? *Now is the time to find out.*

Examine the patient for evidence of cardiac or respiratory disease, and in particular for cardiac valvular disease (for which prophylactic antibiotics will be required to protect the patient during surgery), hypertension (look at the optic fundi), and left-sided or right-sided cardiac failure with elevated venous pressure, ankle or sacral oedema, liver enlargement, or basal crepitations. Look at the shape of the chest and the activity of the respiratory muscles for evidence of acute or chronic airway obstruction or respiratory failure. Palpate the trachea to see if it is displaced by fibrosis, by the collapse of all or part of a lung, or by pneumothorax. Percuss the chest wall for areas of dullness that may be due to the collapse of a lung or effusion. Listen for wheezing or rales, which may indicate generalized or localized bronchial obstruction.

The abdomen also deserves your attention. Enlargement of the liver may point to disease caused by a high alcohol intake or to other forms of liver disease that can affect the patient's response to anaesthetic drugs. (A cirrhotic liver is usually shrunken and impalpable.) If you are in a part of the world where malaria is prevalent, check the patient's spleen; hypersplenism can lead to problems in blood coagulation. Distension of the abdomen by intestinal gas, ascites, an abdominal tumour, or even an enlarged uterus can cause severe respiratory embarrassment when the patient lies down. (Obstetric anaesthesia, which has special problems and requires special consideration, is dealt with in Chapter 13.)

At this stage in the examination you may have diagnosed several problems in addition to the one that requires surgery. Decide whether further investigations (for example laboratory tests, X-ray examination, and electrocardiography) are needed. A routine X-ray examination of the patient's chest is not necessary if there are no abnormal symptoms or signs referable to the chest, but measurement of haemoglobin concentration or erythrocyte volume fraction should be routine if the patient is having a general anaesthetic or anything other than a minor operation under conduction anaesthesia.

When all the results are available, ask yourself three further questions:

- Can the patient's condition be further improved by preoperative treatment?
- Should the patient be referred for treatment of underlying conditions, for example anaemia, infections, or dietary deficiency, before surgery?
- What anaesthetic technique is most suitable for the patient? (See Chapter 11.)

A patient in need of an operation may be a candidate for blood transfusion, either because of pre-existing anaemia, or because major blood loss is possible. Each patient must be assessed, and the potential benefits of blood transfusion balanced against possible risks such as transmission of HIV, hepatitis viruses, malaria, and other infectious diseases. A patient with well compensated anaemia and good cardiac and respiratory function can normally withstand anaesthesia well even with a haemoglobin level as low as 70–80 g/litre. For planned surgery, if donated blood is either unavailable or unsafe, up to 3 units of the patient's own blood can sometimes be taken in advance (in stages, with oral iron given to assist new blood formation); this blood is then re-transfused at or after the time of operation. In many places, patients' hepatitis and HIV status can be routinely checked preoperatively so that the risk of staff becoming infected can be minimized.

When you have decided on your anaesthetic technique, explain briefly to the patient what will happen, with reassurance that you will be present all the time

Preoperative Checklist

Part 1

Hospital no.
Surname
First name

Date
Ward
Blood group

History

SERIOUS ILLNESSES	Cardiovascular Respiratory Other systemic Diabetes Haemoglobinopathies
CURRENT HEALTH	
CURRENT/RECENT DRUGS	Corticosteroids Anticoagulants Antibiotics Antihypertensives Antidiabetics
ALLERGIES	
ADVERSE REACTION TO PREVIOUS ANAESTHETIC (SELF/RELATIVE)	
RECENT FLUID LOSSES	Bleeding Vomiting Diarrhoea Other
RECENT NUTRITION	Food: normal/abnormal Fluids: normal/abnormal
DATE OF LAST MENSTRUAL PERIOD	

Fig. 5.1. Preoperative checklist.

Preoperative Checklist

Part 2

Physical examination

GENERAL CONDITION
- Conjunctivae
- Anaemia
- Hydration
- Teeth
- Cyanosis

UPPER AIRWAYS
- Obstruction: likely/unlikely
- Intubation: probably simple/difficult

RESPIRATORY SYSTEM
- Cough
- Wheeze
- Dyspnoea
- Sputum

SHAPE OF CHEST
- Normal expansion
- Percussion

FINDINGS ON AUSCULTATION

CARDIOVASCULAR SYSTEM
- Heart rate
  - regular/irregular
- Blood pressure
- Precordium
  - Left ventricle: normal/enlarged
  - Right ventricle: normal/enlarged
  - Thrills
  - Murmurs
- Functional diagnosis
- Signs of cardiac failure

ABDOMEN
- Thin/obese
- Distension
- Ascites

Further investigations ordered & results

Special preparations needed

Planned anaesthetic technique

to look after breathing and the function of the heart and to make sure that he or she feels no pain. Also tell the patient what to expect on awakening, for example oxygen, an intravenous infusion, a nasogastric tube, or surgical drains. A few minutes of explanation and kindness in your approach will relieve many of the patient's anxieties and make your task as anaesthetist much easier.

Finally, prescribe any premedication you wish the patient to have (see below).

In making a simple and efficient preoperative assessment, you may find a checklist (as shown in Fig. 5.1) helpful. A single chart could combine a preoperative checklist, an anaesthetic chart (as in Annex 3), and a postoperative instruction sheet.

Preoperative fasting and fluids

For non-emergency patients having general or major conduction anaesthesia, if there is no reason to suspect abnormal gastric or intestinal function, the periods of preoperative fasting which are generally accepted as safe are as follows:

Adults: No solid food for 6 hours, liquids up to 3 hours preoperatively
Children: No solid food for 6 hours, milk up to 4 hours, water up to 2 hours preoperatively.

For emergency patients and all obstetric patients, preoperative fasting should be for at least 4 hours (unless surgery cannot safely be delayed for this period), and the anaesthetic technique used should be suitable for a patient with a full stomach (e.g. rapid sequence induction with cricoid pressure).

Premedication for anaesthesia and surgery

A patient about to undergo surgery is usually given premedication for one or more of the following reasons:

- to provide sedation and relieve anxiety associated with fear of the unknown (although this is unnecessary in children under 2 years old);
- to provide sedation to make it easier to use conduction anaesthesia;
- to provide analgesia if the patient has pain before the operation or to provide a background of analgesia during and after the operation;
- to suppress secretions, especially before the use of ether or ketamine (the drying agent atropine is given for this purpose and may also be used to block vagal activity and prevent bradycardia, especially in children);
- to reduce the risk of aspiration of acid gastric contents if gastric emptying is impaired, for example in pregnancy (in such cases antacids are given orally).

Drugs for premedication should be given in a dose related to the patient's weight and general condition. The normal routes for premedication are intramuscularly 1 hour or orally 2 hours before anaesthesia.

Many anaesthetists prefer to avoid heavy opiate premedication if anaesthesia is to include spontaneous respiration of ether/air mixtures.

The following drugs are widely used:

Opiate analgesics	morphine 0.15 mg/kg intramuscularly pethidine 1.0 mg/kg intramuscularly

Sedatives	diazepam 0.15 mg/kg orally or intramuscularly temazepam 0.3 mg/kg orally
Anti-emetic	metoclopramide 0.2 mg/kg orally (maximum 10 mg)
Vagolytic antisialogogue	atropine 0.02 mg/kg intramuscularly or intravenously at induction (maximum 0.5 mg)
Antacid (adult dose)	sodium citrate 30 ml (0.3 mol/litre).

6

General anaesthesia

Inhalational anaesthesia forms the basis of most general anaesthetic techniques in common use, although intravenous techniques are an alternative. There are two different systems available for delivering anaesthetic gases and vapours to the patient. In the draw-over system, air is used as the carrier gas to which volatile agents or compressed medical gases are added. In the continuous-flow system air is not used, but compressed medical gases — oxygen and nitrous oxide when available — pass through flow meters (rotameters) and vaporizers to supply anaesthetic to the patient.

Continuous-flow anaesthetic machines (usually known as Boyle's machines) can be used only if there is a guaranteed supply of oxygen and preferably of nitrous oxide also. These gases are not always easy to obtain, and nitrous oxide is expensive. A potential hazard in using compressed gases is that, should the oxygen cylinder run out during anaesthesia, the machine may continue to deliver nitrous oxide alone, and this will rapidly kill the patient. Various alarms and interlock devices have been fitted to Boyle's machines to minimize this risk, but none is fully satisfactory. A draw-over system, which is open to the atmosphere at one end, cannot deliver substantially less than the atmospheric concentration of oxygen, which is 20.9% by volume, and can be used even if no cylinders of gas are available. In many cases supplementation of the inspired gases with oxygen is desirable, and this is easily and very economically done with a draw-over system. Draw-over systems can be used with either cylinders or oxygen concentrators as their oxygen source; Boyle's machine can function only if cylinders are available.

The draw-over system is capable of producing first-class anaesthetic and surgical conditions. In contrast to continuous-flow systems, which were first used around 1912, the modern draw-over apparatus developed in the 1940s and 1950s has proved extremely reliable, easy to understand and maintain, and economical in use. It should be the first choice for inhalational anaesthesia in all small hospitals and should be one of a variety of techniques in regular use in teaching hospitals. However, some small hospitals and many larger ones already possess continuous-flow machines, and a description of their use is therefore included in this chapter.

The state of anaesthesia can be produced by several different types of drug with differing properties. The aim is to provide a pleasant induction and lack of awareness for the patient, using a technique that is safe for both patient and anaesthetist and that provides good operating conditions for the surgeon. Unfortunately, the ideal anaesthetic drug with all the desired qualities does not exist. It is common practice, therefore, to combine several drugs, each of which provides a single component of anaesthesia. This can be represented diagrammatically as a triangle whose corners represent sleep (unconsciousness), muscular relaxation, and analgesia (lack of response to painful stimulation) (Fig. 6.1).

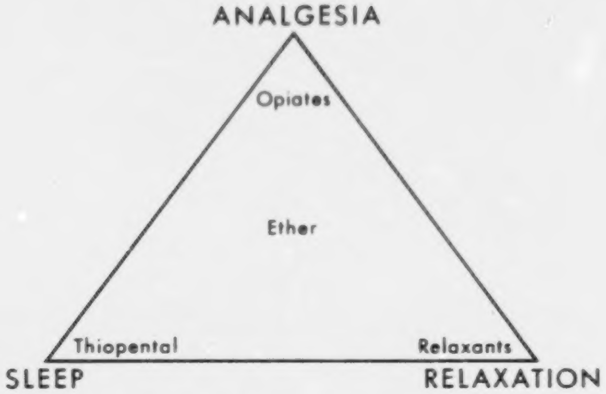

Fig. 6.1. Balanced anaesthesia represented as a triangle.

Certain drugs, thiopental for example, produce unconsciousness without relaxation or analgesia, which makes them suitable for use only for inducing anaesthesia. In contrast, ether produces a mixture of sleep, analgesia, and relaxation, but because of its pungent smell and high solubility in blood it is rather inconvenient and slow (though safe) for induction of anaesthesia. The muscle relaxants produce muscular relaxation alone, and may therefore be used to provide good surgical relaxation during light anaesthesia, allowing the patient to recover rapidly at the end of anaesthesia. Opiate drugs like morphine and pethidine produce analgesia with little change in muscle tone or level of consciousness. Several combinations of techniques and drugs are available, and the choice of the most suitable combination for any given patient and operation calls for careful thought and planning.

Before induction of anaesthesia

Anaesthesia is often compared to flying an aeroplane — most crashes happen during take-off and landing — so special care is needed during induction and recovery.

Checking the patient

Before starting, check that you have the correct patient scheduled for the correct operation on the correct side. The responsibility for this check belongs to both anaesthetist and surgeon. The surgeon should mark the operation site with an indelible marker before the patient comes to the operating theatre. Check that the patient has been properly prepared for the operation and has had no food or drink for the appropriate period of time. It is normal to withhold solid food for 6 hours preoperatively, but in babies a milk feeding can be given up to 4 hours preoperatively. Clear fluids are regarded as safe up to 2 hours preoperatively if gastrointestinal function is normal. (For induction of anaesthesia for emergency surgery when the patient possibly has a full stomach, see p. 76.) Measure the patient's pulse and blood pressure, and try to make him or her as relaxed and comfortable as possible. Make sure that an experienced and trained assistant is available to help you with induction. *Under no circumstances should you induce anaesthesia when alone with the patient.*

Checking your equipment

It is vital to check your equipment before you give an anaesthetic: the patient's life may depend on it. Copy out the appropriate check-list from Annexes 1 and 2 and hang it permanently on any anaesthetic apparatus you use.

First make sure that all the apparatus you intend to use or might need is actually available. If you are using compressed gases, check the pressure in the cylinders in use and also in the reserve cylinders. Check that the anaesthetic vaporizers are connected properly with no leaks and no loose or missing filling caps and that the breathing system that delivers gas to the patient is securely and correctly assembled. If you are at all uncertain about the breathing system, try breathing through it yourself (with the supply of anaesthetic agents turned off). Check the functioning of the resuscitation apparatus (which must always be present in case of a gas supply failure), the laryngoscope, the tracheal tubes (by inflating the cuff to check for leaks), and the suction apparatus. You must also ensure that anaesthesia is induced with the patient lying on a table or trolley that can be rapidly tilted into a head-down position to cope with possible sudden hypotension or vomiting.

Draw up the drugs you intend to use into labelled syringes and make sure that any drugs you might need are actually available.

Before inducing anaesthesia, ensure adequate intravenous access by inserting an indwelling needle or cannula into a large vein; for major surgery an intravenous infusion of an appropriate fluid should be started immediately.

The choice of technique for induction of anaesthesia lies between:

- intravenous injection of a barbiturate, ketamine, or propofol
- intramuscular injection of ketamine
- inhalational induction (i.e. "gas induction").

Intravenous induction

This is pleasant for the patient and easy for the anaesthetist. It will be the technique of choice in many cases, but care is always needed, as it is relatively easy to give an overdose or to stop the patient from breathing. If breathing stops, the patient may die unless you can easily ventilate the lungs with a face mask or tracheal tube. The first rule of intravenous induction is that it must *never* be used in a patient whose airway is likely to be difficult to manage. For such a patient inhalational induction is inherently much safer, or the patient should be intubated while still awake. Intravenous induction will also suddenly reveal any preexisting dehydration, hypovolaemia, or hypotension — these must be corrected preoperatively or there will be a dangerous fall in blood pressure on injection of the drug.

Induction with a barbiturate (see also p. 81)

The barbiturate thiopental is presented as ampoules of yellow powder that must be dissolved before use in sterile distilled water or saline to make a solution of 2.5% (25 mg/ml). Higher concentrations are dangerous, especially if accidentally injected outside a vein, and should not be used. The normal practice is to give a "sleep" dose by injecting the drug slowly until the patient becomes unconscious and loses the eyelash reflex. The average sleep dose in a healthy adult is 5 mg/kg of body weight, but in sick patients much less is needed. An overdose of thiopental will cause hypotension by depressing the vasomotor centre and respiratory arrest by depressing the respiratory centre.

Injection of thiopental is almost always painless. If the patient reports pain, stop injecting immediately, because the needle is probably outside the vein and may even have entered an artery. (Avoid injection into the elbow if possible, because it is easy to enter the brachial artery by mistake.) If you do accidentally inject an artery, leave the needle there and, for an adult patient, inject into the artery 5 ml of 1% lidocaine, 100 mg of hydrocortisone, and 1000 International Units of heparin to prevent arterial thrombosis; then remove the needle and infiltrate a further 5 ml of lidocaine around the artery.

Methohexital can be used as an alternative to thiopental. It also comes as a powder and should be made up as a 1% solution (10 mg/ml). The average sleep dose is around 1 mg/kg of body weight. Patients are slightly more likely to complain of pain during injection, even with a correctly placed needle, though the pain is not usually severe. The incidence of pain is higher when small veins on the back of the hand are used.

Once the patient loses consciousness stop injecting the barbiturate drug. In old or sick patients, the circulation time from arm to brain is slow, so give the drug more slowly to avoid an overdose. After induction the responsibility for protecting the patient's airway and breathing is yours. In most cases, you will want to protect the airway by inserting a tracheal tube.

Induction with propofol

Propofol is a recently introduced intravenous anaesthetic which can be used for induction of anaesthesia. It is a white emulsion which, like thiopental, produces unconsciousness in one arm–brain circulation. Its depressant effects on respiration and blood pressure are greater than those of thiopental, especially if it is injected quickly, and after injection there is often a respiratory arrest requiring manual inflation of the patient's lungs. Injection is usually painful unless a small amount of lidocaine (20 mg of lidocaine in 200 mg of propofol) is added just before injection. The chief advantage of propofol is in the quality of recovery — patients are much less drowsy postoperatively, and this is useful if they have to leave hospital the same day. The normal induction dose of propofol is 2–2.5 mg/kg of body weight. At present it is much more expensive than thiopental.

Induction with ketamine (see also p. 81)

Induction with ketamine is similar in principle to induction with thiopental, and the same precautions apply. The average induction dose is 1–2 mg/kg of body weight. (The standard formulations are 50 mg/ml and 100 mg/ml, but be sure to check which one you have.) The patient's appearance as he or she loses consciousness is different from when barbiturates are used, and the patient may not appear to be "asleep". The eyes may remain open, but the patient will no longer respond to your voice or command or to painful stimuli. If you try to insert an oropharyngeal airway at this stage the patient will probably spit it out. Muscle tone in the jaw is usually well maintained after ketamine has been given, as is the cough reflex. A safe airway is not guaranteed, since if regurgitation or vomiting of gastric contents occurs, there is still severe danger of aspiration into the lungs.

After induction with ketamine, you may choose to proceed to a conventional inhalational anaesthetic, with or without relaxants and intubation. For short procedures, increments of ketamine may be given intravenously or intramuscularly every few minutes to prevent the patient responding to painful stimulation. This method of anaesthesia is simple, but produces no muscular relaxation, and ketamine is not a cheap drug. If your supplies are limited, try to reserve ketamine for cases where there are few suitable alternatives, for example for short procedures in children when access to the airway may be difficult.

Intramuscular induction

Ketamine may also be given by intramuscular injection to induce anaesthesia. With a dose of 6–8 mg/kg of body weight, induction occurs within a few minutes, followed by 10–15 min of surgical anaesthesia. At 8 mg/kg of body weight,

63

ketamine produces a marked increase in salivary secretions, necessitating injection of atropine (which can be mixed with the ketamine). Subsequent increments of ketamine can be given intramuscularly or intravenously, as required. Intramuscular doses last longer and wear off more slowly. If ketamine is used as the sole anaesthetic agent, patients sometimes complain afterwards of vivid dreams and hallucinations. The incidence of such hallucinations can be reduced by giving diazepam either before or at the end of anaesthesia. Hallucinations do not occur if ketamine is used only for induction and is followed by a conventional anaesthetic. If you use intramuscular ketamine it is usually necessary to give atropine to prevent the excessive salivation which otherwise occurs.

Inhalational induction

This is the technique of choice for inducing anaesthesia when the patient's airway is difficult to manage. If you use an intravenous induction for such a patient and "lose" the airway, the patient may die of hypoxia if you are unable to ventilate the lungs. In contrast, inhalational induction can proceed only if the patient has a clear airway down which the anaesthetic can pass. If the airway becomes obstructed, the patient will stop taking up further anaesthetic and redistribution of the drug in the body will lighten the anaesthesia. As this happens the patient will clear the obstruction. Inhalational induction is also preferred by some children, who may object to needles.

Inhalational induction is an important technique and should be practised regularly; despite the many points to be considered, it is simple and requires only patience, care, and observation. Either draw-over or continuous-flow apparatus can be used for inhalational induction (Fig. 6.2), but slightly differing techniques are needed.

Induction using draw-over apparatus

The recommended agents for inhalational induction with draw-over apparatus are ether (for example from the EMO or PAC vaporizer) or halothane (for example from the PAC or Oxford Miniature Vaporizer (OMV)). If oxygen is available, it should be added with a T-piece, as shown in Fig. 7.9 (p. 66). The draw-over apparatus and breathing system are assembled as shown in Fig. 7.7 (p. 63). If halothane is in use, the vaporizer should be downstream from the ether vaporizer.

The smoothest induction is effected by applying a well fitting face mask gently and beginning induction with halothane (which is preferable because unlike ether it is not an irritant). Gradually increase the concentration, say by 0.5% every five breaths, until the patient is asleep (maximum 2–3% halothane). Then slowly turn on the supply of ether and increase the concentration by 1% every five breaths. The respiratory stimulant effect of ether will increase the uptake of both itself and the halothane. If the patient coughs or holds his or her breath, reduce the ether concentration immediately by a third of its setting and try again. When you reach 8% ether, turn off the halothane. You may then proceed to laryngoscopy and intubation after further deepening the anaesthesia by increasing the ether concentration to about 15%. Watch for the onset of paralysis of the lower intercostal muscles to show that the anaesthesia is deep enough. The addition of oxygen is desirable at least until intubation has been achieved. If your attempt at intubation does not succeed, reapply the face mask and deepen the anaesthesia again for a second attempt. If intubation is still impossible, *but* you can maintain a clear airway using a face mask, you may proceed to give anaesthetic with the face mask, using ether at 7–10% to provide relaxation if required. If relaxation is not required, reduce the ether concentration to 6%. With ether at this concentration your patient can, if necessary, manage without

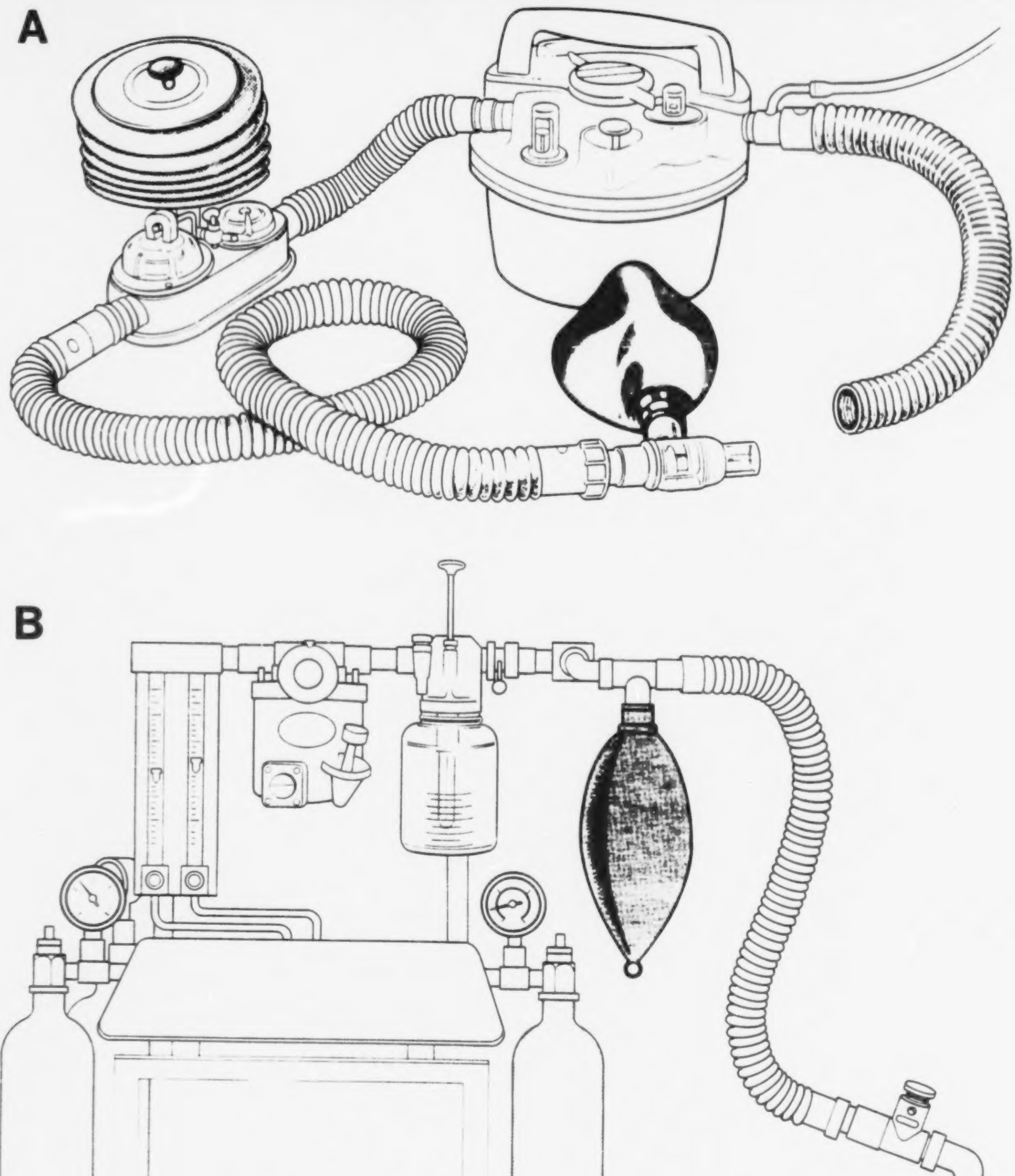
A
B
Oxygen cylinders
Nitrous oxide
WHO 89080

Fig. 6.2. Apparatus for inhalational anaesthesia. (A) Draw-over system; (B) continuous-flow (Boyle's) anaesthetic machine.

oxygen supplementation, provided that he or she is not very young, old, ill, or anaemic.

Take special care if halothane is used as an alternative to ether; it depresses the heart and respiration. Additional oxygen should be given if at all possible and a tracheal tube and controlled ventilation used for all but brief operations.

Induction using a Boyle's machine

First check your machine, making sure that you have adequate supplies of gas for the duration of anaesthesia (see check-list in Annex 2). *Oxygen should be used at a concentration of not less than 30%* to allow for any leaks or inaccuracy of the flow meters (rotameters). For safety, the use of an oxygen analyser at the machine's gas outlet is strongly recommended. If you are using a one-way breathing valve at the patient end of the circuit, you should set the total gas flow (oxygen or oxygen plus nitrous oxide) higher than the patient's minute volume — say 9 litres/min. With a Magill breathing system, the flow may be reduced to 5 litres/min. If you are using halothane as your main volatile agent, place the face mask on the patient's face and gradually increase the halothane concentration up to a maximum of 3%, reducing it to 1.5% after the patient has settled or after intubation. If you are using ether (without halothane) as your volatile agent, it is easier to turn on the supply of ether from the Boyle's bottle with the face mask held about 30 cm above the patient's face. Gradually lowering the mask over the next minute will slowly increase the ether concentration in the inspired gas and is usually well tolerated. Once the mask is in contact with the face, slowly increase the ether concentration over a few minutes. The patient will be ready for intubation when you can see paradoxical (i.e. inward) movement of the lower ribs during inspiration.

7

Clinical use of anaesthetic equipment[1]

This chapter deals with the safe *clinical* use of the sort of anaesthetic equipment best suited for and most likely to be found in a district hospital. It should be read in association with Chapter 15 which deals with the technical aspects of equipment maintenance and gas supplies. All equipment will rapidly deteriorate and become dangerous unless it is regularly inspected, maintained, and repaired, so the anaesthetist working alone in a small hospital must take responsibility both for care of patients and the upkeep of apparatus.

Draw-over apparatus

Two fundamental pieces of equipment are needed for draw-over inhalational anaesthesia: a vaporizing device for the anaesthetic and an SIB to ventilate the patient's lungs. These must be linked together and to the patient by a breathing system containing one or more one-way valves (to prevent the patient from breathing out through the vaporizer). The breathing system must connect to the patient's airway at its outlet via a breathing valve and face mask or tracheal tube, and the inlet to the system must be open to the atmosphere to allow air to be drawn in, either by the patient's inspiratory effort or by the recoil of the SIB. Various types of apparatus are commercially available for draw-over use; some examples are shown in Fig. 7.1.

Vaporizers

For effective and safe use in a draw-over system, a vaporizer must have a low resistance to gas flow (since air must be drawn through it by the patient's inspiration), and it must be capable of accurately delivering the required concentration of vapour despite the wide fluctuations in flow that occur during the inspiratory period. The range of vaporizers currently in use includes the EMO (Epstein, Macintosh, Oxford), OMV (Oxford Miniature Vaporizer), and PAC series (Fig. 7.2 & 7.3). The OMV and EMO have a wide application, as they can also be used with continuous-flow anaesthetic systems. Vaporizers with a high internal resistance (for example the "Tec" series, Boyle's bottle, and Drager Vapor) are completely unsuitable for draw-over use and must never be used for draw-over anaesthesia, as the patient cannot breathe through them.

When a volatile anaesthetic liquid is vaporized, heat is lost as latent heat of vaporization. If this heat loss is not compensated for, the vaporizer and contents will

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[1] In some cases, the breathing valves, ventilating apparatus and vaporizers described in this chapter (and elsewhere in the book) have been identified by the manufacturer's name or trademark. However, this does not imply that such products are endorsed or recommended by WHO or the author in preference to others of a similar nature that are not mentioned. Rather, the specific products mentioned represent those that are known to the author to be in common use in district hospitals with limited resources. In the event that there are others in common use, WHO would be pleased to be so informed for the purpose of including a description of their use in future editions of this book.

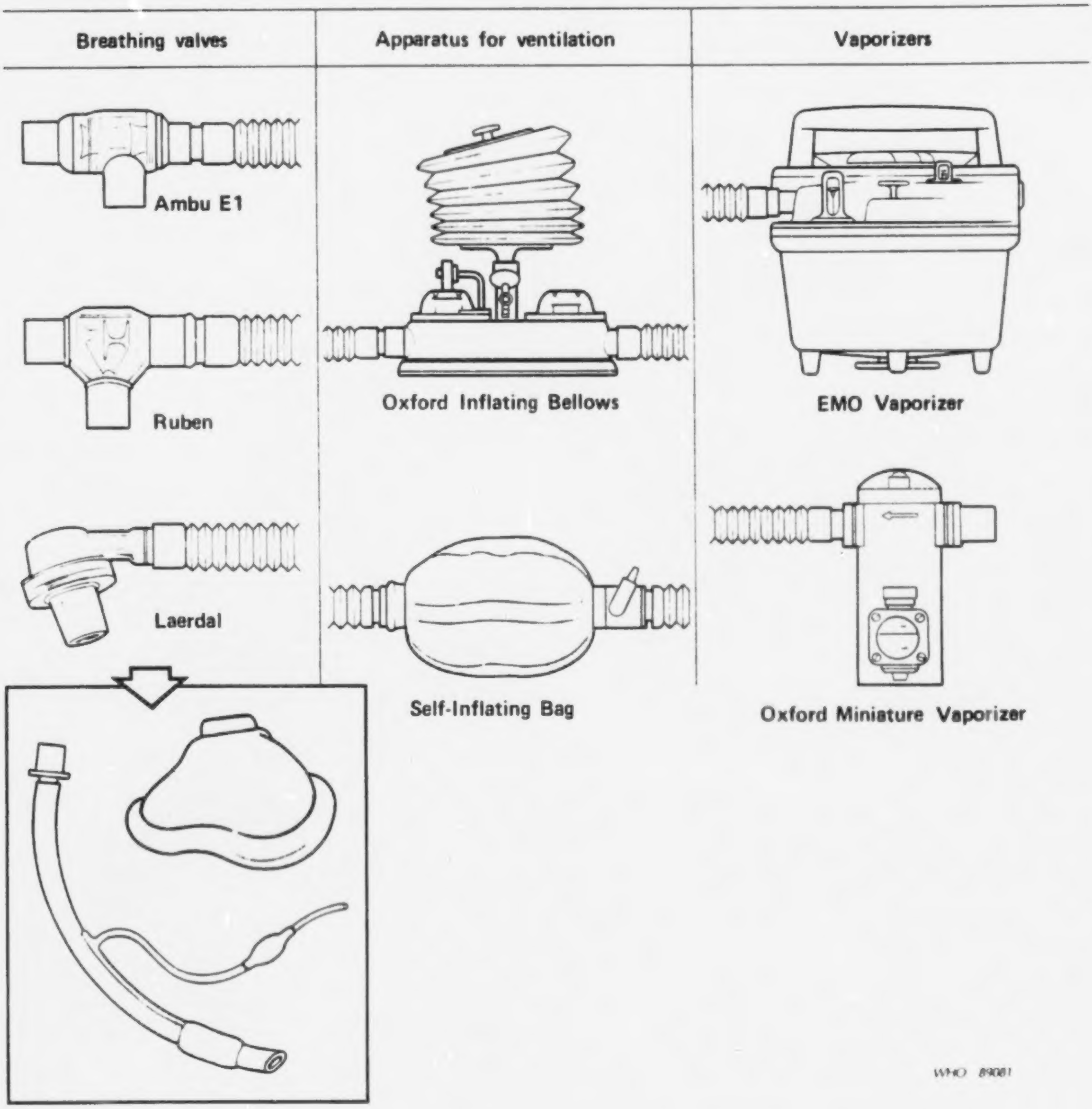
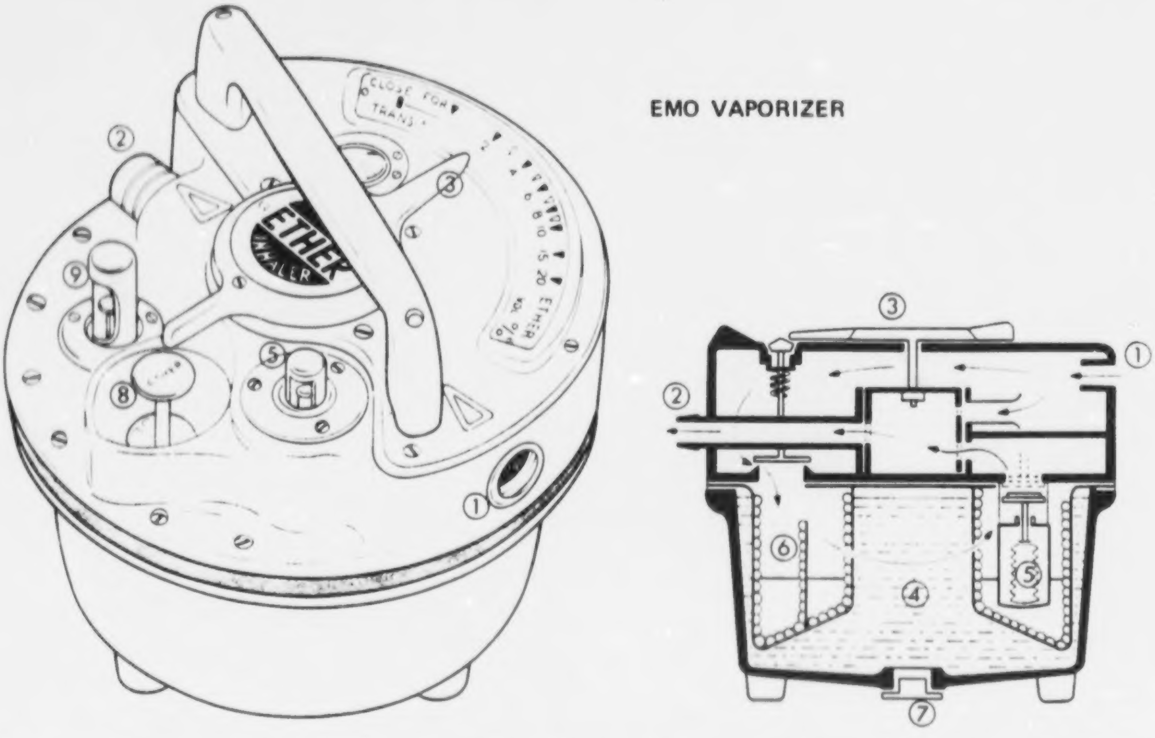

Breathing valves
Apparatus for ventilation
Vaporizers
Ambu E1
Ruben
Laerdal
Oxford Inflating Bellows
Self-Inflating Bag
EMO Vaporizer
Oxford Miniature Vaporizer
WHO 89081

Fig. 7.1. Draw-over anaesthesia systems.

cool. This will result in a rapid fall-off of the concentration of vapour delivered, since the vapour pressure of the anaesthetic falls with temperature. To prevent this from occurring or to minimize its effects, most draw-over vaporizers have a thermal compensation or buffering system or both. Thermal buffering is the provision in the vaporizer of a mass of substance of high specific heat capacity (usually copper or water) that resists sudden changes in temperature. Thermocompensation is achieved by building into the design of the vaporizer a thermostatically operated valve to control the amount of air entering the vaporizing chamber and keep constant the concentration of vapour delivered. The EMO ether vaporizer (Fig. 7.2) uses both thermocompensation and thermal buffering, with water as the heat reservoir. (New vaporizers are sent from the factory with the water chamber empty, and the first user must fill the water chamber in accordance with the manufacturer's instructions.) The thermocompensation valve of the EMO is automatic and can be seen through a small window on top of the vaporizer, which also indicates whether the vaporizer is within its thermal


EMO VAPORIZER
①
②
③
④
⑤
⑥
⑦
⑧
⑨
CLOSE FOR TRANS
ETHER
INHALER
2 4 6 8 10 15 20 ETHER
VOL %

OXFORD MINIATURE VAPORIZER

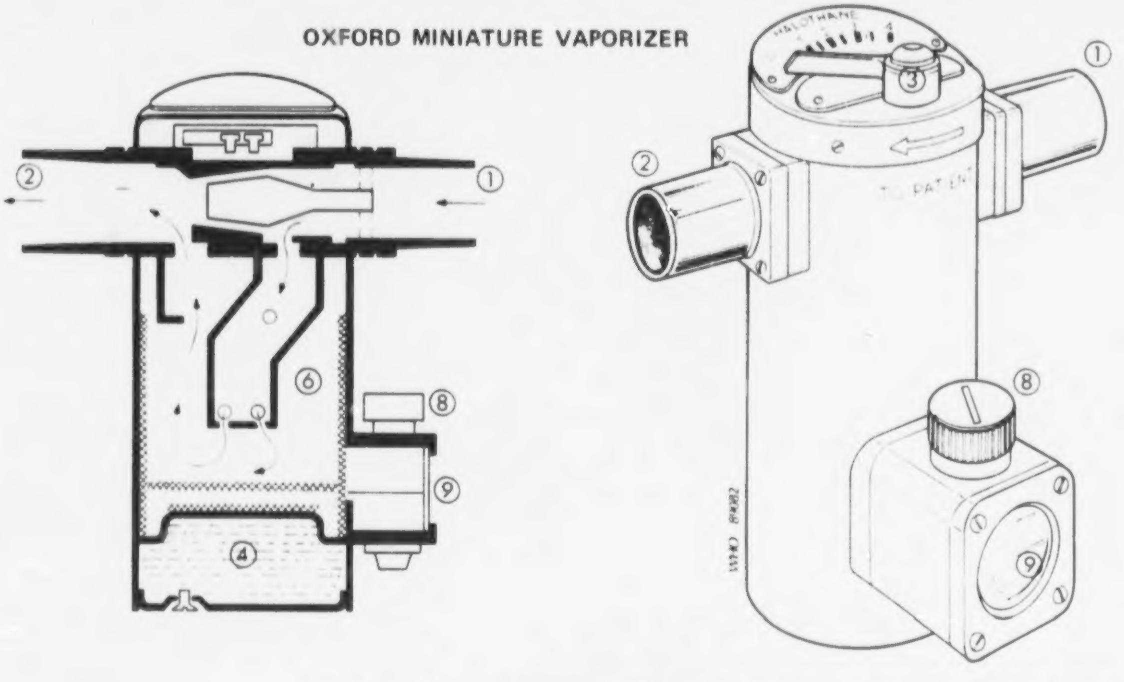

①
②
③
④
⑥
⑧
⑨
HALOTHANE
1 2 3 4
TO PATIENT
WHO 89082

Fig. 7.2. Draw-over vaporizers (EMO & OMV). (1) Inlet port, (2) outlet port, (3) concentration control, (4) water jacket, (5) thermocompensator valve, (6) vaporizing chamber, (7) filling port for water, (8) filling port for anaesthetic, (9) anaesthetic-level indicator.

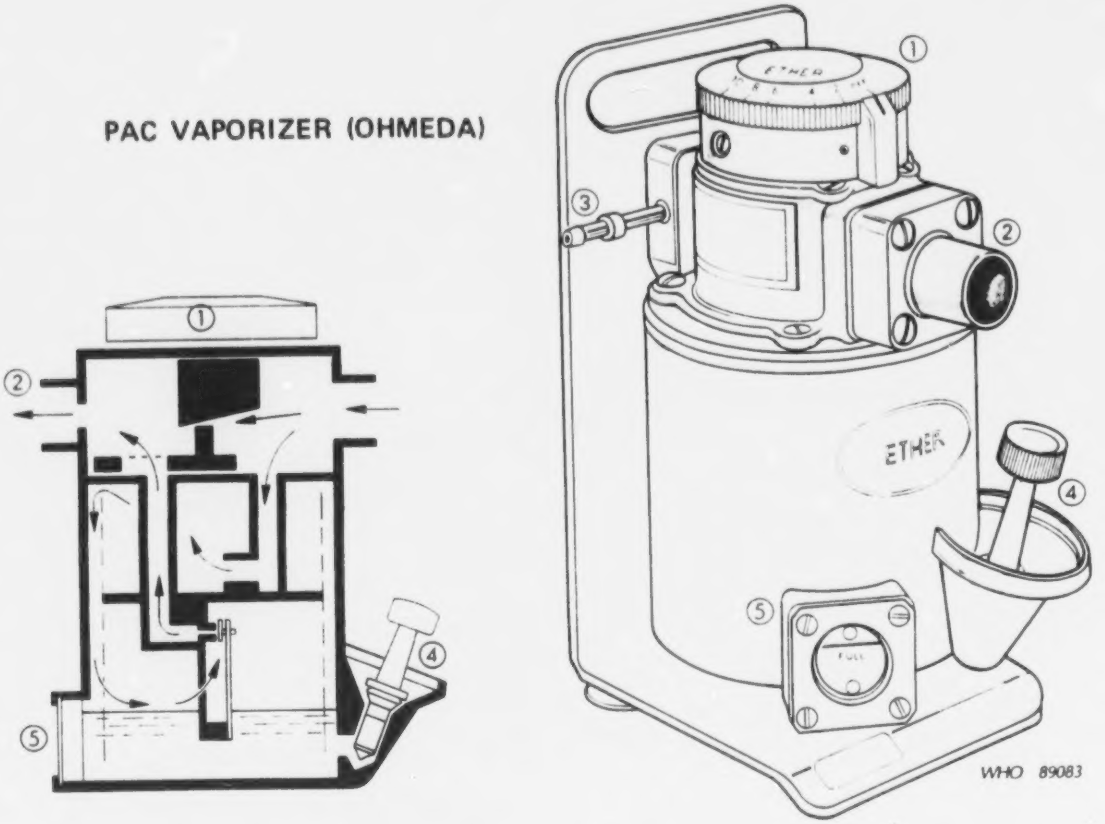


Fig. 7.3. **PAC draw-over vaporizer. (1) Concentration control, (2) outlet connector and one-way valve (inlet opposite), (3) port for oxygen enrichment, (4) filling port, (5) filling gauge.**

working range of 10–30 °C (Fig. 7.4). In normal use a black ring should show at the window. If the vaporizer overheats, for example by being left in direct sun on a hot day, a red ring also appears, and the vaporizer must be cooled before use. If the vaporizer becomes too cold, for example by being left in an aircraft luggage bay, the black ring disappears, and only an aluminium disc is visible; the vaporizer must then be allowed to warm up before use. If the black ring is not showing and the vaporizer does not appear cold, the thermocompensation valve (TC valve) may have fractured and need replacement (normal valve life is about 10 years). Replacement is relatively simple and does not require return of the vaporizer to the manufacturer.

The PAC series vaporizers use automatic thermocompensation and, if their accuracy is to be ensured, should be serviced only by a manufacturer's agent. The OMV does not have full thermocompensation, but changes in temperature are minimized by thermal buffering with a mixture of water and antifreeze, which is put into the core of the vaporizer during manufacture and needs no further attention from the user. The output concentrations of the vaporizer are controlled with a pointer that moves over a graduated scale.

It is possible to connect two vaporizers in series, but *never* connect any vaporizer containing halothane to the *inlet* port of the EMO, since if halothane enters the EMO it rapidly causes severe corrosion. It is perfectly safe to connect a halothane vaporizer such as an OMV to the outlet port of the EMO (Fig. 7.5). In fact, the OMV was designed to be used in this position.

During anaesthesia, it may become necessary to refill the vaporizer with anaesthetic liquid. You must first turn the concentration control to the zero position

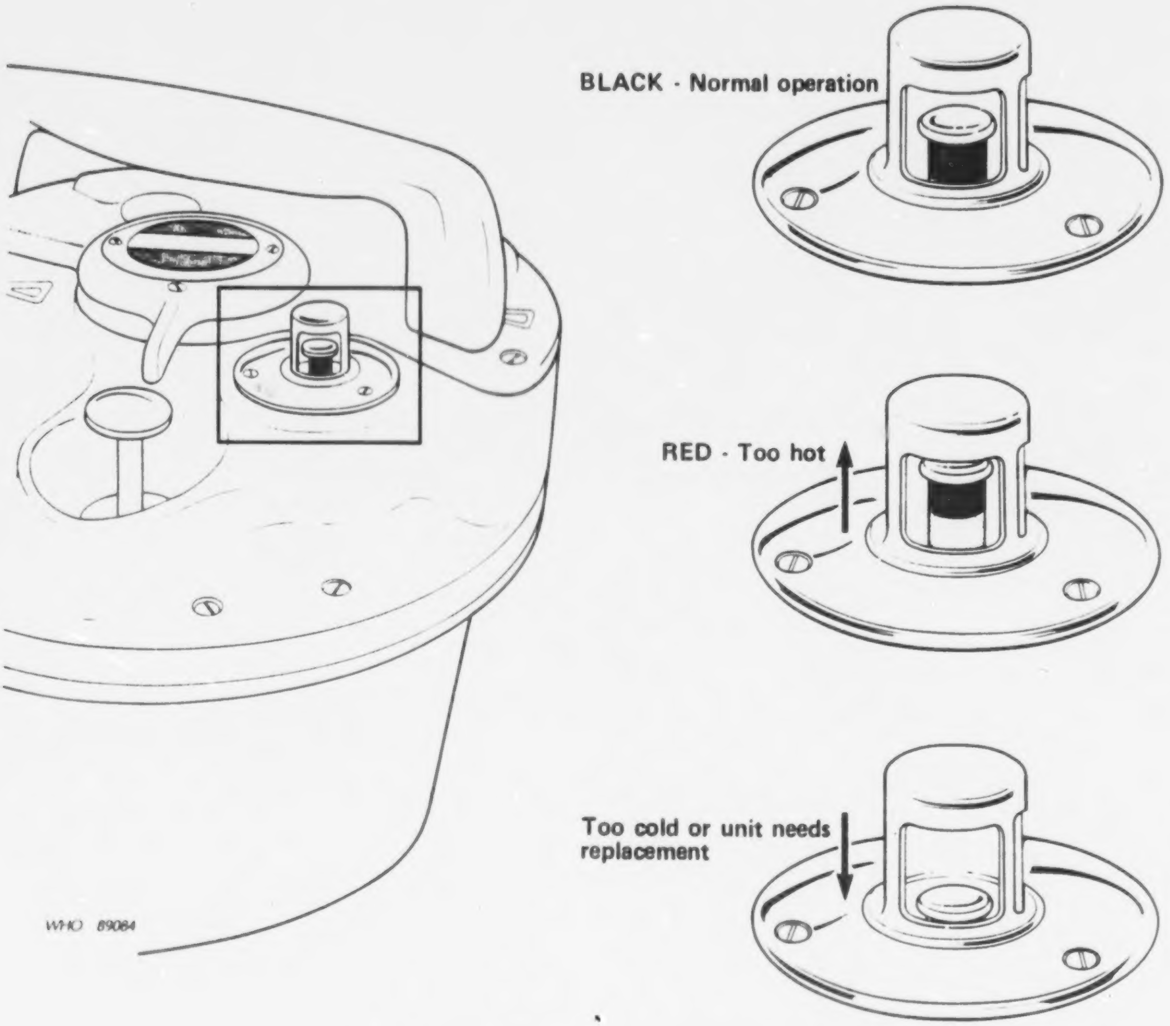

BLACK - Normal operation
RED - Too hot
Too cold or unit needs replacement
WHO 89084

Fig. 7.4. Thermocompensation valve and temperature indicator on the EMO vaporizer.

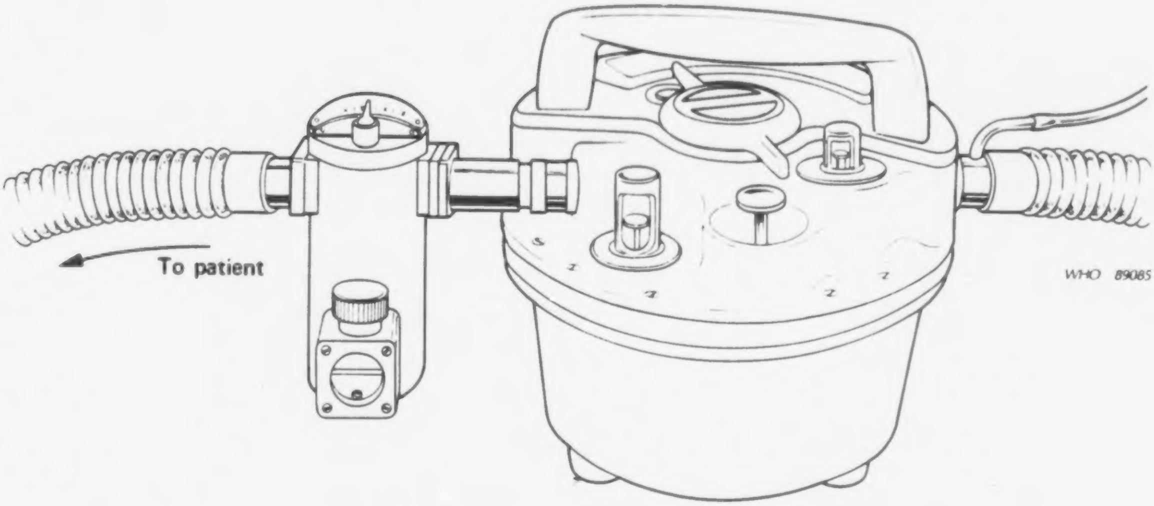
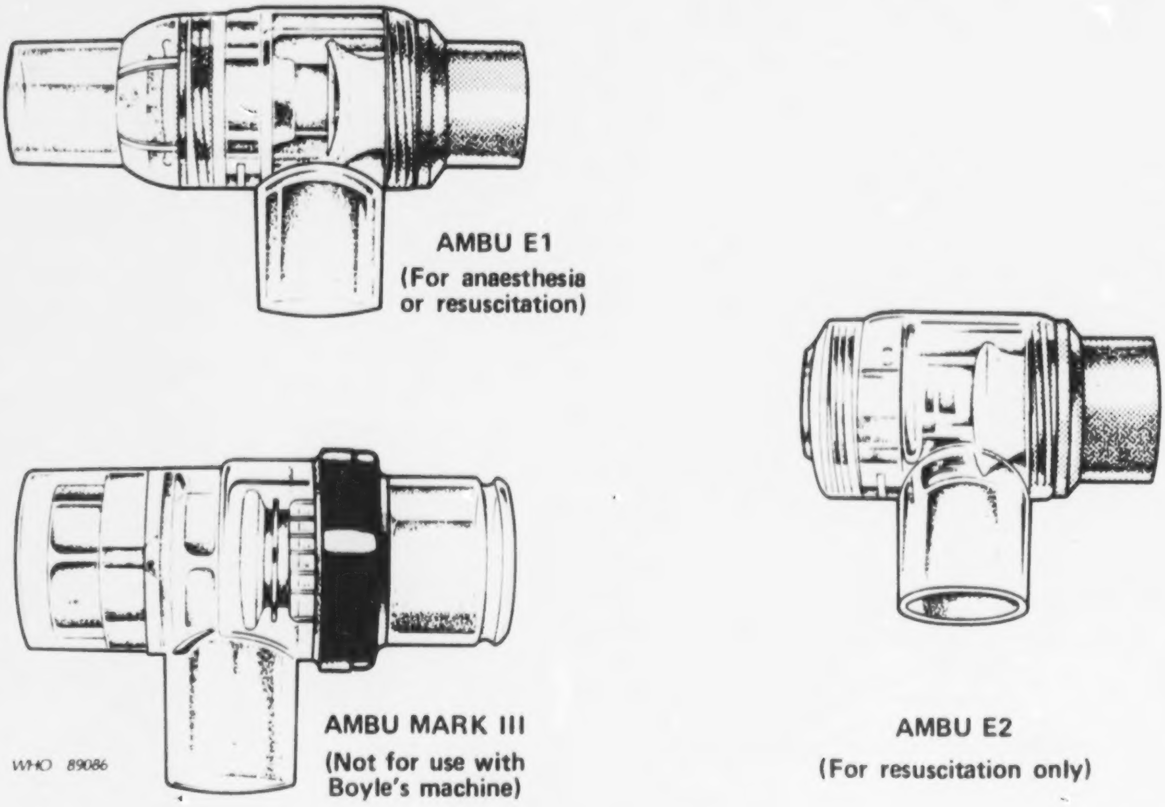

To patient
WHO 89085

Fig. 7.5. The OMV connected to the outlet port of the EMO.



AMBU E1
(For anaesthesia or resuscitation)

AMBU MARK III
(Not for use with Boyle's machine)

AMBU E2
(For resuscitation only)

WHO 89086

Fig. 7.6. Types of Ambu valve.

before opening the filling port. If you fail to do so, air will be drawn into the vaporizing chamber and a dangerously high concentration of anaesthetic will be delivered to the patient. For the same reason, you must never use a vaporizer that has no filling plug or that has any route through which air can enter accidentally, for example a broken glass window on the filling gauge.

Breathing systems and an important note about valves

The purpose of the breathing system (formerly called the breathing circuit) is to deliver anaesthetic vapour from the vaporizer to the patient, to pass the patient's expired gas into the atmosphere, and to provide a method of giving controlled ventilation (IPPV) when muscle relaxants are in use or for resuscitation. The breathing system contains several valves: one valve connects the patient's airway to the system; another one or two are built into the SIB; and certain vaporizers, for example the PAC system, have their own one-way valves.

In principle, at least two valves are needed in a breathing system to make gas flow in the correct direction. A universal breathing valve (see Fig. 2.10, p. 18) at the patient's end of the system ensures that, during spontaneous or controlled ventilation, gas always reaches the patient from the vaporizer and passes out into the atmosphere (preferably through an antipollution system). You are strongly recommended to use a universal breathing valve for all patients. [Beware of confusing the Ambu E1 (anaesthesia) valve with the E2 (resuscitation only) valve (Fig. 7.6). The E2 valve is of no use for anaesthesia, as it allows the patient to breathe in atmospheric air from downstream. The anaesthetic valve has two sets of yellow valves inside, the resuscitation valve only one.]

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A second one-way valve is needed to prevent gas from flowing into the vaporizer, rather than into the patient, during IPPV. In the PAC system, this

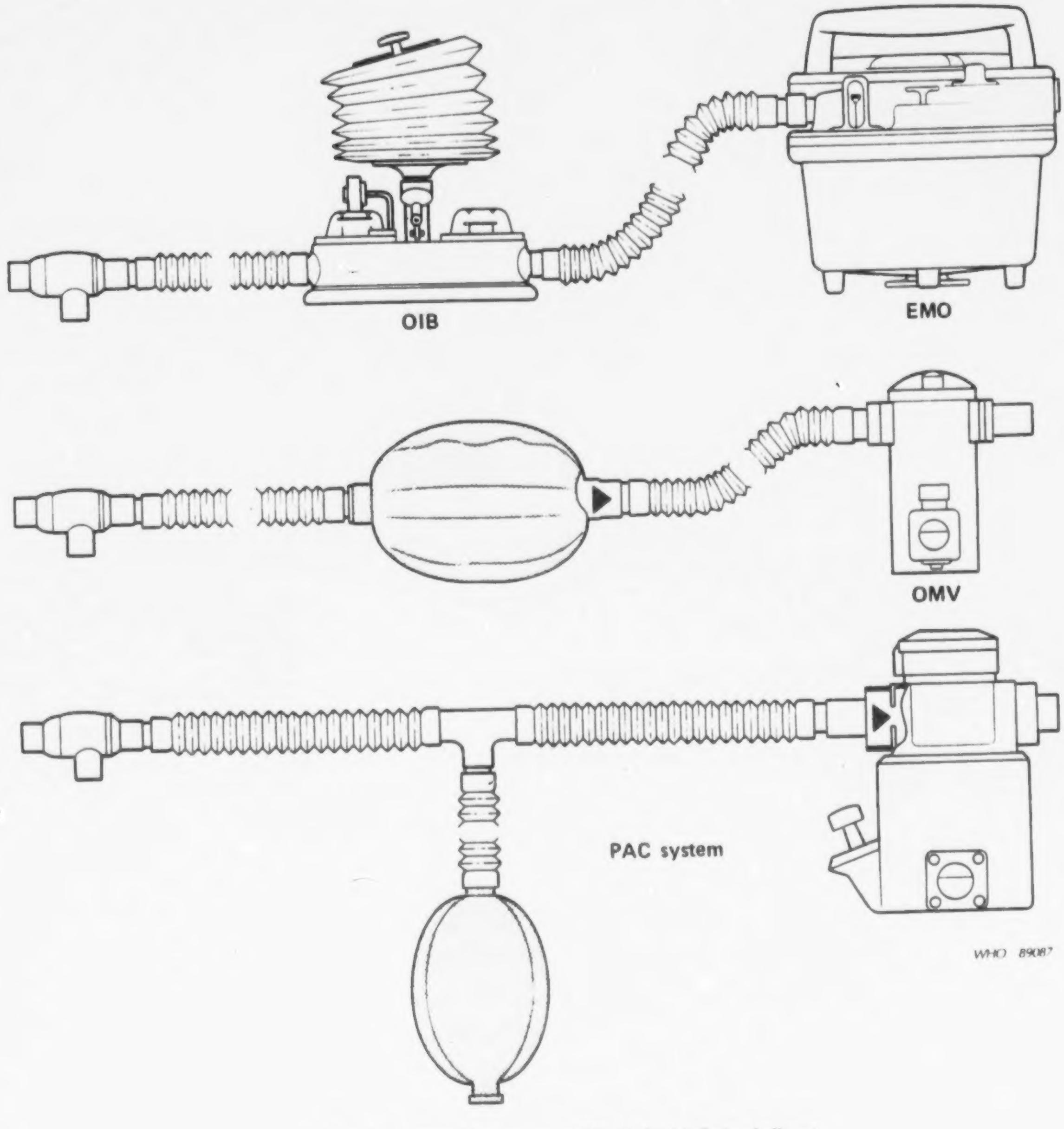

Fig. 7.7. Breathing systems (OIB, Oxford inflating bellows).

second valve is built into the vaporizer itself (see (2) in Fig. 7.3, p. 60) and the SIB can be mounted on a T-piece. The EMO does not have a built-in one-way valve and must therefore be connected in series with the SIB, which does have its own valve to prevent gas flowing backwards to the vaporizer (Fig. 7.7).

The breathing tubes that form the system are connected to the vaporizers and SIB by conically tapered metal or plastic connectors (ISO 22-mm diameter, 1-degree taper). Connections should be made firmly without excessive force. Study the diagrams of breathing systems in Fig. 7.7. It will help you understand the function of the breathing valve if you draw your own diagram of it from the manufacturer's instructions. If you are unsure about the assembly of the system, try breathing through it yourself (with the vaporizers turned off!).

Self-inflating bags or bellows

Several of the different types of SIB available are shown in Fig. 2.9 on p. 16. All SIBs have a one-way valve upstream of the bag or bellows; gases can enter the SIB through this valve, but must leave through the other end of the SIB in the direction of the patient. The Oxford inflating bellows also has a one-way valve located downstream from the bellows.

The Oxford inflating bellows should be placed in the breathing system between the vaporizer and the breathing valve. During storage, the bellows is held down by a light internal clip, which is released by pulling upwards on the knob on top of the bellows. An internal spring will then tend to keep the bellows at about a third of its maximum capacity. The patient is free to inspire through the bellows.

Because the system has a low resistance to flow, only a small movement of the bellows will be noticed, since air enters the bellows almost as fast as it leaves when the patient breathes in. Fig. 7.7 shows some possible arrangements of vaporizers and breathing systems.

During controlled ventilation, lift the bellows slightly from the "rest" position and press down to inflate the patient's lungs. Inspiration should be started sharply to ensure that the breathing valve snaps smartly into the inspiratory position. Do not press down too hard at the end of inspiration, or the clip will engage and lock the bellows down. It is not necessary to lift the bellows to its maximum capacity, as this would produce a tidal volume of 2 litres, far in excess of the patient's need. At the base of some bellows is a small tap or nipple labelled "oxygen inlet", which was originally intended to allow the addition of oxygen during resuscitation. It is not compatible with modern universal breathing valves and should not be used (for the recommended technique of adding oxygen with an SIB, see Fig. 2.11, p. 19). For paediatric use, a small-volume bellows is available that can be exchanged for the adult one on the same base and valves and used with an Ambu "Paedi-valve".

To allow a universal breathing valve to work properly with the Oxford inflating bellows, you must disable the one-way valve located downstream from the bellows, i.e. at the end of the bellows nearest the patient, by clipping the magnet supplied over the valve, thus lifting the valve disc to the top of the chamber. As a permanent alternative, the valve disc could be removed altogether. If you do not disable this valve, the breathing valve may stick and the patient will be harmed.

In some hospitals you may find that there are no universal breathing valves and that only a Heidbrink valve (also called an expiratory or pop-off valve) is available. This valve has no mechanism for preventing the patient's expired gas from flowing backwards to the SIB. It is not recommended for IPPV, but it can be used for spontaneous breathing with an Oxford inflating bellows (but not with any other SIB). In these circumstances, both the valves on the Oxford inflating bellows are needed, so remove the magnet from above the downstream valve and place it in the holder at the side. The valve is then free to move and will prevent the patient's expired gas from passing back into the bellows (Fig. 7.8).

Ambu, Cardiff, Laerdal, and similar bags can be used in a similar way to the Oxford inflating bellows. The bag is fitted with an inlet valve that allows gas or atmospheric air to enter at one end; for anaesthesia this valve is connected with a breathing tube to the vaporizer. This type of bag must always be used with a universal breathing valve, and never with a Heidbrink or a "resuscitation only" valve. Some bags have a port to allow direct connection of an oxygen supply, but, as with the Oxford inflating bellows, this is not recommended for oxygen enrichment; a T-piece and reservoir should be used instead.

With the PAC system, a non-return valve is incorporated in the vaporizer itself and the SIB is mounted on a T-piece limb, which makes it easier to handle than

74

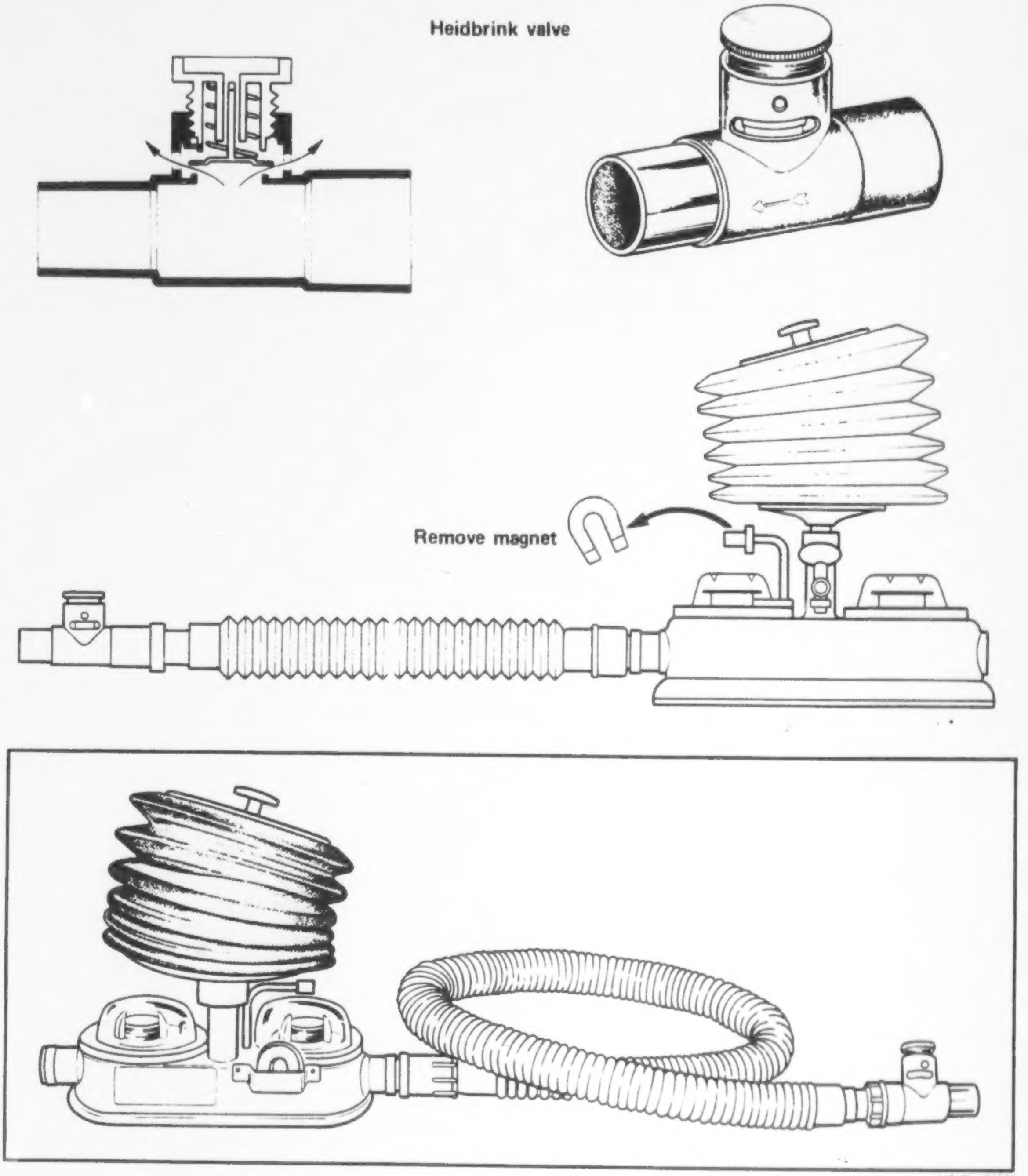

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Fig. 7.8. Use of the Heidbrink valve with the Oxford inflating bellows after removal of the magnet.

an in-line bag (Fig. 7.7). A universal breathing valve must always be used for both spontaneous ventilation and IPPV.

Adding oxygen to the draw-over system

Air contains 20.9% oxygen and is perfectly adequate to oxygenate a healthy patient receiving draw-over anaesthesia, particularly if ether (which stimulates both respiration and cardiac output) is in use or if controlled ventilation is given with light general anaesthesia and a muscle relaxant.

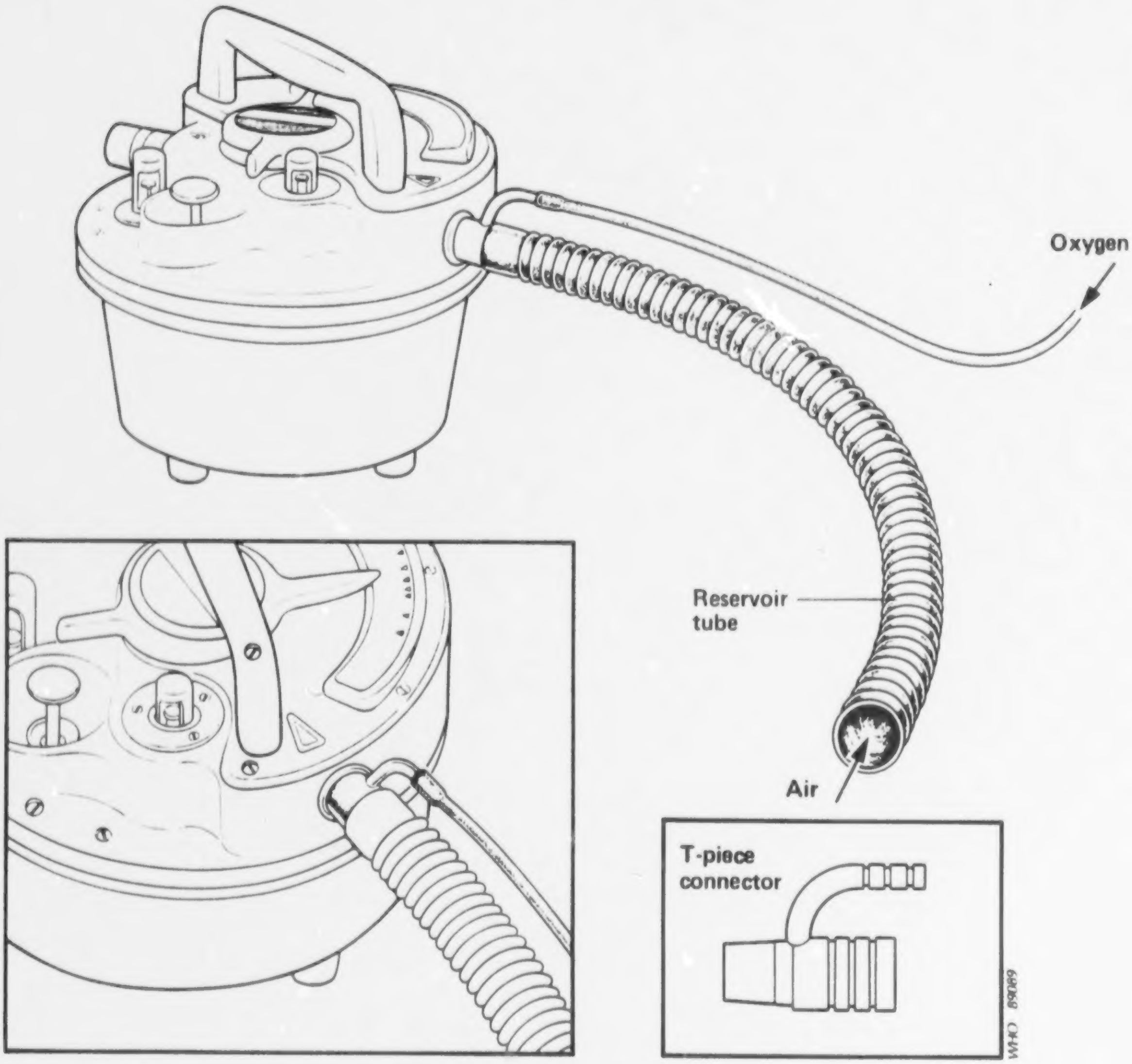

Fig. 7.9. Addition of oxygen with a T-piece and reservoir tube.

Oxygen should always be added

- if the patient is very young, old, sick, or anaemic
- if agents that cause cardiorespiratory depression, such as halothane, are used.

Oxygen is usually available, even if only in limited quantities. Air (the carrier gas) already contains 20.9% oxygen, and oxygen enrichment is very economical in that the addition of only 1 litre/min can increase the oxygen concentration in the inspired gas to 35–40%. With oxygen enrichment at 5 litres/min, a concentration of 80% can be achieved. Industrial-grade oxygen, for example as used for welding, is perfectly acceptable for the enrichment of a draw-over system and has been widely used for this purpose. (Industrial and medical oxygen are both prepared by the same process — the fractional distillation of air.)

To add oxygen to the breathing system, use a T-piece and reservoir tube at the vaporizer inlet (Fig. 7.9). If a ready-made T-piece with reservoir is unavailable, you can easily make an alternative using a small-bore oxygen tube threaded into a large-bore tube (Fig. 2.11B, p. 19). Connect the T-piece and reservoir tube (or your improvised alternative) to the vaporizer inlet and turn on the oxygen supply. In this way the oxygen that flows from the cylinder during expiration is not wasted, but is stored in the reservoir tube for the next inspiration. The reservoir tubing should of course be open to the atmosphere at its free end to allow the entry of air, and it should be at least 30 cm long.

Oxygen concentrators

A full description of oxygen concentrators, which can provide a reliable supply of oxygen from room air using only mains electricity, is given in Chapter 15. Oxygen concentrators are suitable for use in all sizes of hospital and can provide oxygen more cheaply than cylinders, in addition to making oxygen available in hospitals where a regular supply of cylinders is difficult to obtain. It is strongly recommended that only those models meeting the Performance Standard described in Chapter 15 should be purchased for use in district hospitals. An up-to-date list of models currently known to meet the Performance Standard is available on request from Blood Safety and Clinical Technology, World Health Organization, 1211 Geneva 27, Switzerland.

Oxygen concentrators designed for use with individual patients normally give a flow rate of up to 4 litres/min of near-pure oxygen at relatively low pressure. This oxygen can be used in exactly the same way as oxygen from a cylinder — e.g. as the supply for T-piece enrichment into a draw-over system or for use with a nasal catheter, prongs, or face mask to give postoperative or ward oxygen. However, the oxygen from a concentrator is at relatively low pressure and cannot therefore be used in a compressed gas (Boyle's) anaesthetic machine. If there is an electrical power failure the oxygen flow from a concentrator will continue only for about a minute, so make sure you have a back-up system for use in such emergencies — either a generator to maintain electrical supply, or a cylinder of compressed oxygen.

Standardization and identification of oxygen cylinders

An international standard exists for the identification of oxygen cylinders, which specifies that they should be painted white. Unfortunately, the standard is widely ignored. Medical oxygen cylinders originating in the United States of America are normally green, while those originating in Commonwealth countries are usually black with white shoulders. Cylinders of industrial oxygen should also be identified clearly, but this is not always the case. Never use any cylinder to supply gas to a patient unless you are sure of its contents.

Oxygen — fire and explosion risks

All operating theatre staff should be concerned about the possibility of fire or explosion risks in the operating theatre as a result of the use of anaesthetic vapours. It is important to distinguish between gas mixtures that are flammable, i.e. can burn, and those that are explosive. Explosions are much more dangerous to both staff and patients. Of the inhalational anaesthetics mentioned in this book, only one (ether) is flammable or explosive in clinical concentrations.

Mixtures of *ether and air* in the concentrations used for anaesthesia are *flammable*, but there is no concentration of ether that will explode when mixed only with air. However, mixtures of *ether with oxygen or nitrous oxide* are *explosive*.

There is no site within the draw-over apparatus itself where ether combustion could start. The point of risk is therefore the place where the patient's expired gas enters the room, before the ether is diluted by air. If you are using 3–5% ether as an anaesthetic in combination with a muscle relaxant, it is likely that the ether concentration in the patient's expired gas will be less than the lowest flammable concentration (2%). When flammable gases are in use, the most likely source of combustion in the operating theatre is the surgical diathermy machine and other electrical apparatus, followed by static electricity, which is unlikely to start a fire, but can trigger an explosion if an oxygen-rich gas mixture is present. *No potential cause of combustion or source of sparking should be allowed within 30 cm of any expiratory valve through which a potentially flammable or explosive mixture is escaping.* The use of diathermy outside this "zone of risk" is generally acceptable, but if explosive mixtures are in use, for example ether/oxygen or ether/nitrous oxide/oxygen, diathermy should be avoided. It should, of course, never be used inside the mouth or thorax if ether is in use.

What reasonable precautions should you take?

If possible, your operating theatre and equipment should be of the antistatic type. This is important in a dry climate, but less so in a humid one where a natural coating of moisture on objects prevents the buildup of static.

Electrical sockets and switches should either be spark-proof or be situated at least 1 m above floor level.

The patient's expired gases should be carried away from the expiratory valve down wide-bore tubing at least to the floor (ether is heavier than air) or out of the operating theatre. Make sure that no one stands on the hose and that there is nothing that could trigger combustion near the end of this tubing. If you use oxygen enrichment during induction, but not surgery, the patient's expired gas will cease to be explosive within 3 min of stopping the addition of oxygen.

Continuous-flow machines

Continuous-flow anaesthetic machines (commonly known as Boyle's machines or simply gas machines) are in widespread use. They rely on a supply of compressed medical gas, either from cylinders attached directly to the machine or piped from a large bank of cylinders or liquid oxygen supply elsewhere in the hospital. The two gases most commonly used are oxygen and nitrous oxide. Cylinders are attached to the machine by a special yoke that prevents the connection of the nitrous oxide supply to the oxygen port and vice versa — the pin-index system. Some older machines may lack this system; be especially careful with them to prevent incorrect connections. Cylinders contain gas at high pressure, which is reduced to the anaesthetic machine's working pressure, usually 400 kPa (4 atmospheres), by a reducing valve (regulator). Each gas then passes through a needle valve at the base of a rotameter. This valve controls the flow of gas to the breathing system, once the cylinder valve has been opened with a key or spanner (wrench) to allow gas to flow out. The gas passes through the flow meter (rotameter), which measures the gas flow by upward displacement of a bobbin in a tube, and along the "back bar" at the top of the machine, where it may be diverted through a vaporizer for the addition of a volatile anaesthetic agent (Fig. 7.10). A separate switch or tap is usually provided to allow for a high flow of oxygen to be delivered to the patient in case of emergency, bypassing the rotameters and vaporizers. Gas is delivered from the common gas outlet at the top or front of the machine, to which a breathing system is connected.

The vaporizers on a Boyle's machine may be of the calibrated, thermocompensated type (for example Fluotec or Acoma) or simple Boyle's bottles, which are usually used for ether (Fig. 7.11). The Boyle's bottle is uncalibrated, and its output declines as the ether becomes cold. It has two controls: a lever that diverts gas from the back bar down a tube into the vaporizer, and a hood that can be depressed to make the gases pass closer to or even bubble through the liquid ether. Always start with the hood up, increasing the concentration with the lever first, and then lowering the hood if necessary. Never bubble anaesthetic gas through any agent other than ether. Remember that with a Boyle's bottle the

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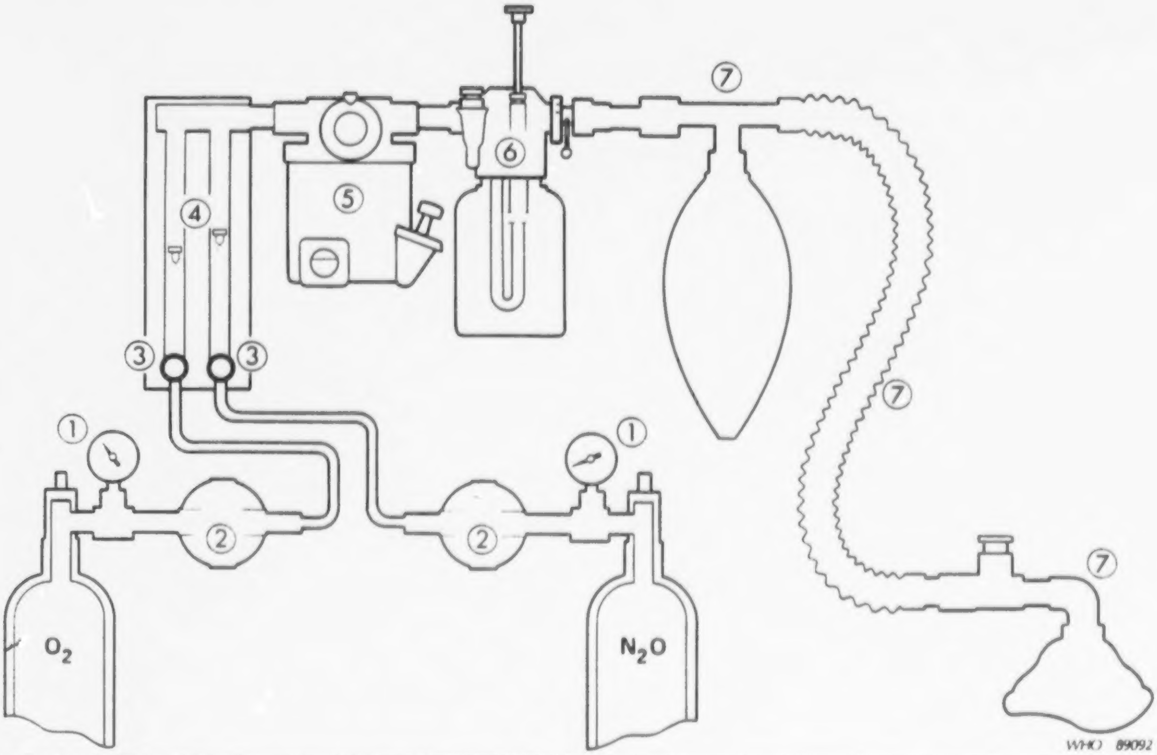

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Fig. 7.12. Gas pathway on a continuous-flow (Boyle's) machine with a compressed gas supply. (1) Pressure gauges, (2) reducing valves, (3) flow-control (needle) valves, (4) flow meters, (5) calibrated vaporizer, (6) Boyle's bottle, (7) Magill breathing system.

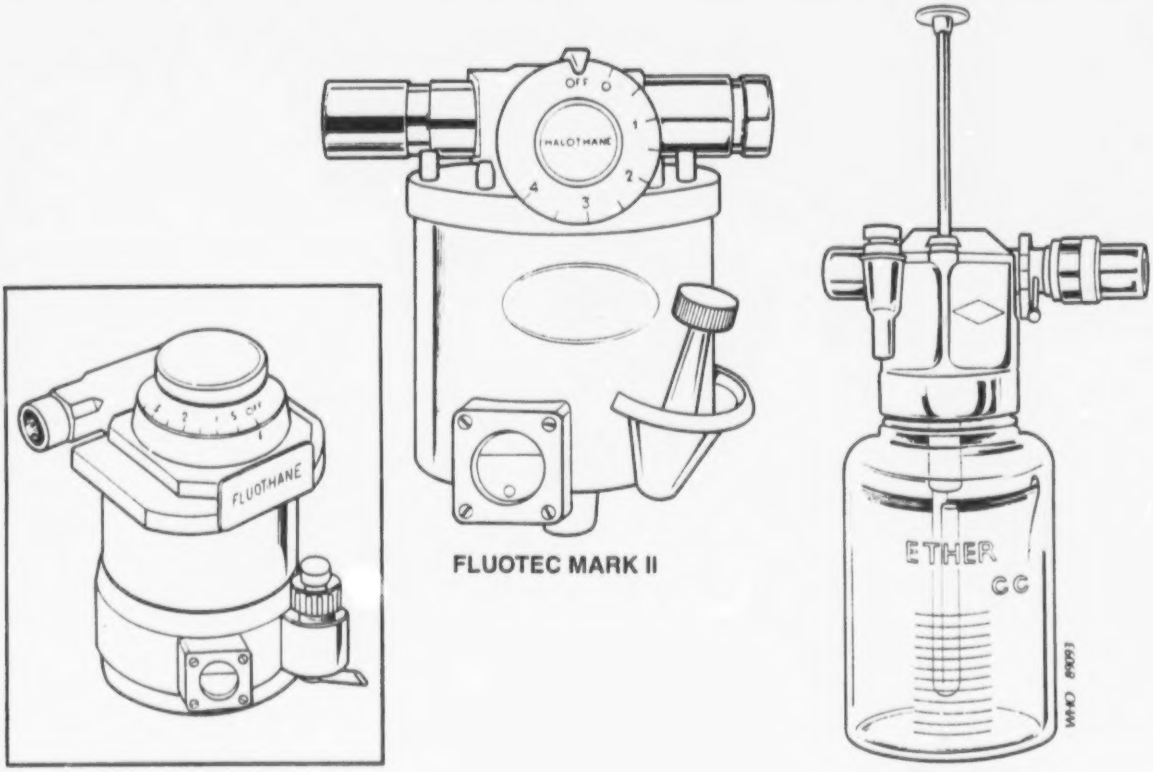
output is neither calibrated nor constant, so you will have to watch the patient with special care. Ether used in a Boyle's machine always produces a potentially explosive mixture.

Because of the danger of giving a patient a hypoxic gas mixture as a result of machine malfunction or human error, it is strongly recommended that an oxygen analyser should always be used with a Boyle's machine to give a continuous display of the inspired oxygen concentration.

The Magill breathing system

This system, which incorporates a Heidbrink valve, is in common use on continuous-flow machines (Fig. 7.12). It is suitable only for spontaneously breathing patients and requires a total gas flow from the flow meters that is approximately equal to the patient's minute volume, for example nitrous oxide at 4 litres/min and oxygen at 2 litres/min for an adult. Always give at least 30% oxygen to provide a margin of safety should there be any leaks or inaccuracy in the flow meters. If you wish to give IPPV with a Boyle's machine, you must use a different breathing system; the Magill system can be modified simply by exchanging the Heidbrink valve for a suitable universal breathing valve such as an Ambu E1 or Ruben valve. Squeezing the reservoir bag will then inflate the patient's lungs. The patient can also take a spontaneous breath from the bag, so the modified system is suitable for both controlled and spontaneous respiration.

DANGER: Do *not* use a Laerdal IV, Ambu Mark III, or other similar valve with low switching-flow in this way, as it will jam on a continuous-flow system.



FLUOTEC MARK II

FLUOTEC MARK III

BOYLE'S BOTTLE

Fig. 7.11. Some vaporizers used on continuous-flow machines with compressed gas supplies.

The circle breathing system

If you have a reliable source of oxygen, you can reduce anaesthetic costs considerably by using a circle system in which some of the patient's expired gas is used again, after removal of carbon dioxide (Fig. 7.13). A special reagent (soda lime) which is a mixture of calcium and sodium hydroxides, is used to absorb the carbon dioxide. When the soda lime is exhausted it changes colour and must be discarded and replaced — 1 kg of soda lime will give about 8 hours' use. Circle systems at district hospitals should not be used with any gases other than oxygen — the source of oxygen can be either a cylinder or a concentrator (with cylinder back-up in case of power failure). Circle systems are relatively complicated and are not recommended for the occasional anaesthetist. For the specialist, full descriptions are to be found in specialist anaesthetic textbooks.

Automatic lung ventilators

For the anaesthetist working without an assistant it can be a great convenience to have a machine provide controlled ventilation of the lungs during surgery — freeing both the anaesthetist's hands for attending to other needs such as monitoring, keeping records, and setting up infusions. Like all machines, ventilators need regular skilled maintenance and attention, and if these are not available it is probably better to use manual ventilation. Many of the ventilators currently available cannot be recommended because of their very high consumption of compressed oxygen (up to 30 litres/min).

The ideal ventilator for a district hospital should:

- use a reliable locally available power source (electricity and/or low flow of oxygen)
- allow any oxygen used for driving purposes to be breathed by the patient
- be easy to understand, use, and repair

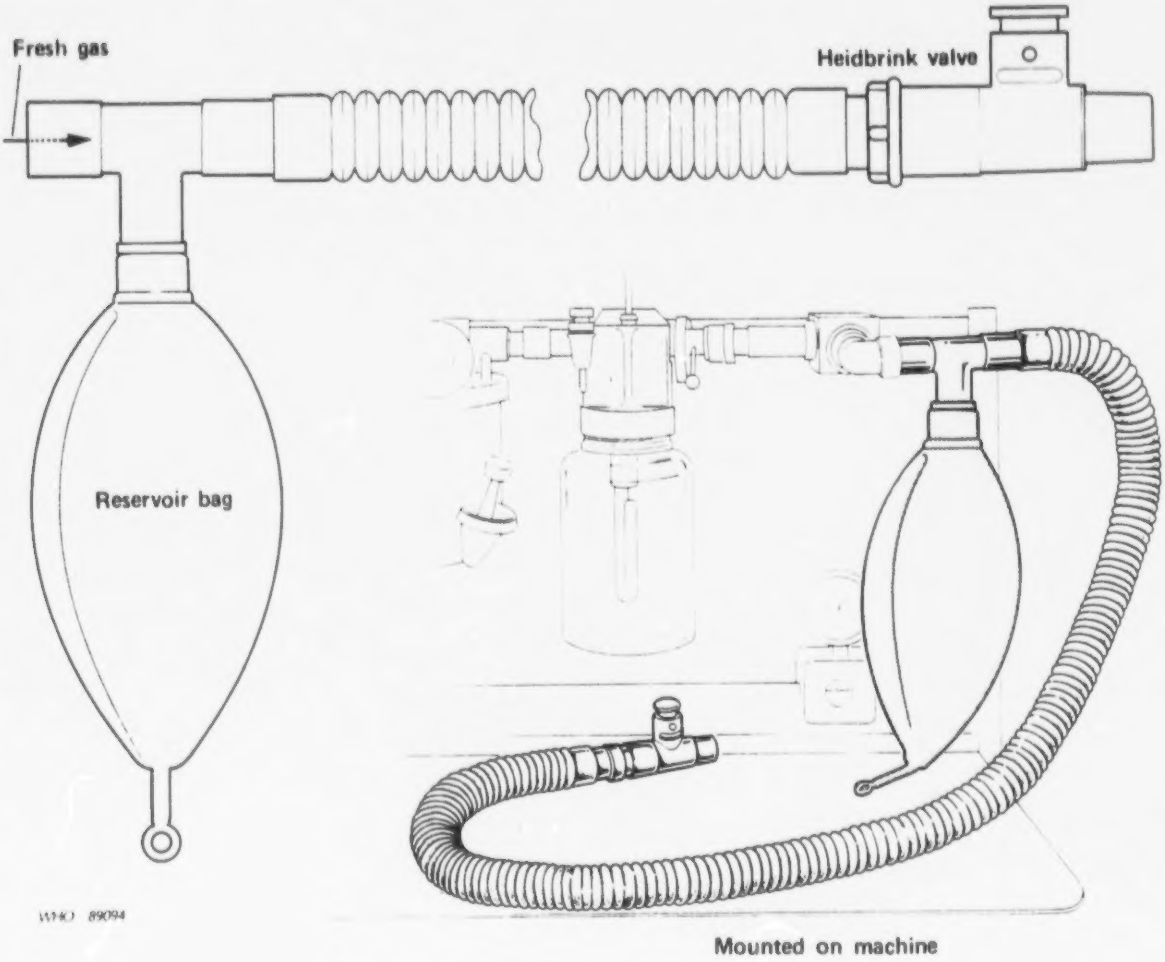


Fig. 7.12. Magill breathing system.

- be capable of ventilating using either draw-over or continuous-flow systems of anaesthesia.

The World Federation of Societies of Anaesthesiologists (8th Floor, Imperial House, 15–19 Kingsway, London WC2B 6TH, England; fax: +41 171 836 5616; e-mail: wfsa@compuserve.com) can advise district hospitals considering the purchase of a ventilator.

Checking your apparatus

Before beginning anaesthesia, you must thoroughly check the machine, with reference to the check-list in Annex 2 (a copy of which should be fixed permanently to your machine). Ensure that you have sufficient compressed gas for the operation, and at least one spare cylinder of oxygen. You must also have an SIB with which to ventilate the lungs should your machine fail. Also check other essential apparatus such as the laryngoscope and sucker. Then assemble the breathing system and test it for leaks by covering the end with your hand and squeezing the reservoir bag. No gas should escape if the Heidbrink valve is closed. (Remember to open it again afterwards!) At least once a month, check the whole machine and any gas hoses for leaks by "painting" suspect areas with soapy water and observing whether bubbles form when you turn on the gas supply. Continuous-

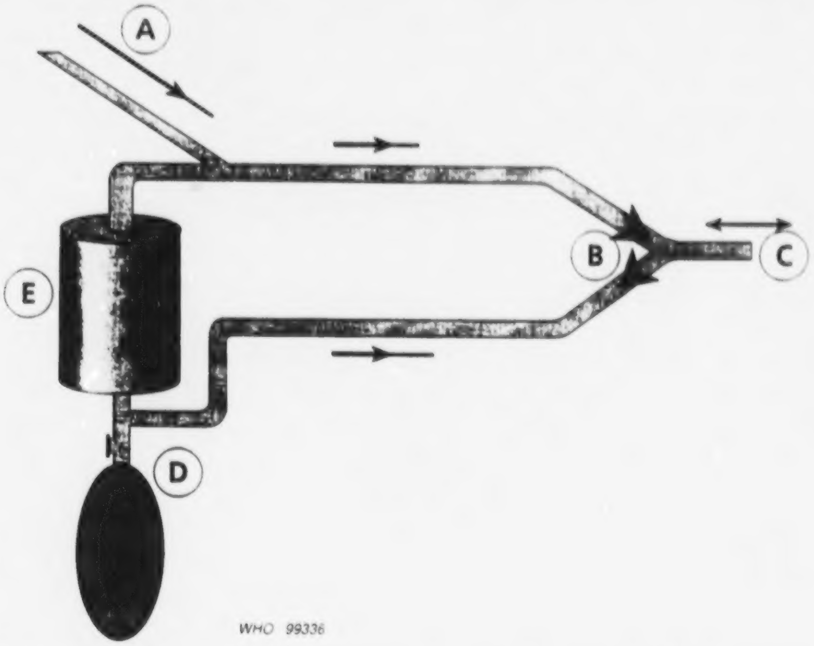


Fig. 7.13. **Diagram of circle breathing system. (A) Oxygen/fresh gas inlet tube, (B) one-way breathing valves, (C) connection to patient, (D) reservoir bag and spill valve, (E) soda lime CO_2 absorber.**

flow machines are prone to leakage because the gases are kept at relatively high pressures inside them.

All types of apparatus should be kept in a clean and dust-free environment, away from extremes of temperature, and covered when not in use. Vaporizers should be drained of anaesthetic if they are unlikely to be used for a week or more. Put a cork or spigot in the end of any gas port or tubing during storage to prevent the entry of insects. Regular cleaning, inspection, and simple maintenance will familiarize you with your equipment, as well as help to keep it in good order. Try to estimate when new parts will be required, and order spares well in advance, before the machine breaks down and leaves you in difficulty.

8

Specimen general anaesthetic techniques

This chapter contains examples of general anaesthetic techniques that should be feasible in small or medium-sized hospitals. The techniques can be used exactly as described or modified to meet the needs of particular patients or circumstances. If you are not a specialist it is better to know a small number of techniques that you can use for most cases. You will be more familiar with these techniques and less likely to make a mistake with apparatus or drug dosage. For more information about the drugs recommended, see Chapter 9. Suggested techniques for conduction anaesthesia are given in Chapter 10.

Levels of anaesthetic services

It is sensible to provide anaesthetic facilities that are appropriate both for the needs of the community served by the hospital and the locally available surgical skills and facilities. In general, as the size of the hospital increases, an increasing range of anaesthetic techniques may become available. *However, this does not mean that simple and effective techniques are out of place in larger hospitals. A large hospital should actively practise the whole range of techniques.* The range of techniques is illustrated in Table 4.

Ketamine anaesthesia

Ketamine given intravenously or intramuscularly as sole anaesthetic

This technique is suitable when muscle relaxation is not required, especially in children. It is also suitable as a "fall-back" technique if your inhalational apparatus (or gas supply for a Boyle's machine) fails or if you have to give a general anaesthetic without inhalational apparatus, for example at an accident for release of a trapped casualty.

1. Give a sedative drug and atropine as premedication (see p. 48).
2. Insert an indwelling intravenous needle or cannula (in a struggling child it is more convenient to delay this until after ketamine has been given intramuscularly).
3. Give ketamine 6–8 mg/kg of body weight intramuscularly or 1–2 mg/kg intravenously (mixed with an appropriate dose of atropine, if not already given in premedication).
4. After intravenous injection of ketamine the patient will be ready for surgery in 2–3 min, and after intramuscular injection in 3–5 min.
5. Give supplementary doses of ketamine if the patient responds to painful stimuli. Use half the original intravenous dose or a quarter of the original intramuscular dose.

Table 4. The range of anaesthetic techniques

Size of institution and probable staffing profile	Available facilities and supplies	Appropriate anaesthetic techniques
Health centre with health worker with little anaesthetic training	Basic	Lidocaine infiltration for simple wound suturing
Small district hospital without specialist anaesthetist	Basic resuscitation Intravenous fluids Possibly oxygen Limited drug range	Lidocaine infiltration Ketamine general Possibly spinal
Larger district hospital with part-time anaesthetist	Full resuscitation Oxygen Inhalational equipment Full drug range, including relaxants	Lidocaine infiltration Ketamine and spinal Inhalational general
Referral centre hospital with full-time specialist anaesthetist	Full resuscitation Oxygen Inhalational equipment Full drug range Basic intensive care	Lidocaine infiltration Ketamine and spinal Inhalational general Variety of conduction techniques

6. At the end of the procedure, turn the patient into the lateral position for supervised recovery in a quiet place.

Ketamine infusion as part of a balanced anaesthetic technique with muscle relaxation

1. After premedication with atropine and pre-oxygenation, induce anaesthesia with a fast-running ketamine infusion containing 1 mg/ml (average adult dose 50–100 ml).
2. Give suxamethonium and intubate the trachea.
3. Maintain anaesthesia with ketamine 1–2 mg/min (more if the patient has not received premedication) and after breathing returns give a "non-depolarizing" relaxant. Ventilate with air, enriched with oxygen if available.
4. At the end of surgery, reverse the muscle relaxation and extubate with the patient awake, as after inhalational anaesthesia.

General inhalational anaesthesia

With intubation, muscle relaxation, and artificial ventilation

This can be regarded as a *universal technique* that is suitable for any operation on an adult patient lasting more than 20 min, especially when rapid recovery is required. It is contraindicated when difficult intubation is anticipated. In such cases, use an inhalational induction/intubation technique (for example as described on pp. 54–56), and then proceed from step 4.

1. Pre-oxygenate the patient by giving a high concentration of oxygen to breathe for at least 3 min, or 10 breaths of pure oxygen at a flow of 10 litres/min from a closely fitting anaesthetic face mask. Loading the lungs with oxygen in this way allows the patient to remain well oxygenated even if tracheal intubation takes several minutes.

   If your oxygen source is an oxygen concentrator it will probably give a flow of no more than 4 litres/min. If you use a T-piece reservoir at the inlet to your breathing system (see p. 17) this will usually allow you to achieve an oxygen concentration of greater than 60%. If a concentration of 80% or more is needed for a short time you will need to pre-fill a large oxygen reservoir from the concentrator — use a large polyethylene bag (e.g. plastic bin liner) for example. If you pre-fill the reservoir for 10 min from the oxygen concentrator it will then provide a flow of 8 litres/min for 5 min which is more than enough for pre-oxygenation. Don't forget to disconnect the reservoir from the T-piece once anaesthesia begins.

2. Induce anaesthesia with a sleep dose of thiopental, usually 5 mg/kg of body weight for an adult, injected intravenously over 30–45 s.
3. Intubate the trachea after producing muscle relaxation with suxamethonium (1 mg/kg of body weight). Ventilate with 10% ether in air for 3 min to establish inhalational anaesthesia.
4. When the effect of suxamethonium wears off, usually after 3–5 min, give an appropriate dose of a non-depolarizing relaxant.
5. Ventilate the lungs with 3% ether in air using a draw-over system and IPPV; surgical diathermy may be used. Halothane 1–1.5% (or another volatile anaesthetic in appropriate concentration) may be used in place of ether, in which case oxygen supplementation is strongly advised.
6. Five minutes before the end of surgery, turn off the ether supply and ventilate with air, enriched with oxygen if possible.
7. At the end of surgery, reverse the relaxant effects with 2.5 mg of neostigmine plus 1 mg of atropine given intravenously. Muscle relaxation cannot be reversed for 20 min following a dose of relaxant. You should normally wait until there is some evidence of returning muscle tone, such as slight respiratory movement, before giving neostigmine and atropine.
8. Continue to assist breathing until the patient breathes deeply and regularly and the mucous membranes are pink.
9. Turn the patient into the lateral position and extubate when he or she is awake, after careful suction of secretions from the mouth and pharynx.

With intubation and spontaneous breathing

This is an alternative technique for operations lasting less than an hour and not requiring relaxation.

1. Pre-oxygenate the patient as above.
2. Induce anaesthesia with a sleep dose of thiopental.
3. Intubate the patient after producing muscle relaxation with suxamethonium. If using ether, ventilate with 10% ether in air until breathing resumes, and then gradually decrease the ether concentration to 6%. The aim of this manoeuvre is to "load" the patient with ether while the suxamethonium is still acting, and thereby prevent coughing and straining when breathing returns.
4. Allow the patient to breathe spontaneously *either* ether 6% in air *or* halothane 1–1.5% with oxygen enrichment at 1 litre/min.
5. At the end of surgery, extubate when the patient is *either* deeply anaesthetized (increase the anaesthetic concentration in the inspired gas to 10% ether or 3% halothane for 2 min before extubation) *or* awake. Always extubate with the patient in the lateral position after careful suction of secretions from the mouth and pharynx. Avoid extubating a lightly anaesthetized patient, e.g. one who coughs but does not respond to commands. Such a patient is most likely to develop laryngeal spasm on extubation.

Without intubation

Intubation may not be necessary for patients requiring anaesthesia for a procedure expected to last 15 min or less (e.g. drainage of an abscess). Such patients must nevertheless be properly prepared and starved preoperatively. *Remember that there is no such thing as a "minor" anaesthetic.*

1. Place the patient in whichever lateral position gives best access to the operation site.
2. Induce anaesthesia with a sleep dose of thiopental.
3. Allow the patient to breathe halothane in oxygen-enriched air from a face mask. Note that, if you have only ether available as an inhalational agent, it is much quicker to use an intubation technique, since it will take 15 min or more to settle the patient with ether given by face mask.

Techniques of total intravenous anaesthesia

In some countries increasing use is being made of total intravenous anaesthesia (TIVA), in which all anaesthetic drugs (including drugs such as relaxants and analgesics) are given by intravenous infusion at a rate precisely controlled by an electronic syringe pump that effectively eliminates the need for a vaporizer. At present the drugs most suitable for such techniques — such as propofol, midazolam, and ketamine — may be too expensive for widespread use for this purpose. It is not possible to substitute cheaper drugs, such as thiopental, as they accumulate to very high levels during continuous infusion. If a suitable range of short-acting drugs becomes available at reasonable prices, TIVA may become more widely accepted and used at the district hospital level.

General anaesthesia for emergency cases

The patient who requires anaesthesia for an emergency operation presents extra difficulties to the anaesthetist, who must make a full preoperative assessment and anticipate any likely problems. The patient may not have been fully prepared or be in an ideal physiological state. Certain pathological states, such as fluid depletion, can and must be rapidly treated before anaesthesia, but others, such as a chest infection, can be treated only within the limits of the time available, as excess delay would cause further deterioration of the patient's condition. Sick patients with poor circulation should receive smaller doses of almost every drug (suxamethonium is an exception — use a normal dose), and you must also allow a longer period for drugs to circulate after giving them intravenously. Be particularly careful with drugs given intravenously and local anaesthetics. Very often, the sicker the patient, the greater the risk associated with using spinal anaesthesia, so general anaesthesia may be preferable.

Patients requiring emergency surgery frequently have a full stomach. In an injured patient, gastric emptying will have stopped at the time of the injury. Patients with intra-abdominal disease and pregnant patients at or near term must also be assumed to have retained gastric contents with a high concentration of hydrochloric acid. If gastric contents enter the lungs during anaesthesia, severe damage and even death are real possibilities. One of your chief concerns must be to prevent this catastrophe. The presence in the trachea of a cuffed tracheal tube is the only sure protection during general anaesthesia. This is one reason that so much stress is laid on tracheal intubation in this book. The anaesthetist's goal is to insert the tube as swiftly and smoothly as possible, while keeping the lungs protected from both active vomiting and passive regurgitation.

The simplest way to intubate is with the patient awake, and this is almost always possible with neonates and infants aged less than 2 months, in whom it is the technique of choice. Many adults, especially if they are sick, will also tolerate intubation while awake if you explain what you intend to do and why. Use a well-lubricated laryngoscope blade, and insert it gently and slowly. When you can see the larynx (it may take a minute or two) pass the tracheal tube through it, trying not to touch the sides of the pharynx on the way down, as this may make the patient gag and you will have to start again. On intubation the patient will probably cough, and your assistant may need to restrain the patient's hands. Immediately after intubation, you can safely induce anaesthesia with thiopental. (For an infant, you need only turn on the supply of inhalational anaesthetic agent.)

Rapid sequence induction

For emergency surgery, many anaesthetists prefer to use a "rapid sequence induction", sometimes called a "crash induction". *The aim is to induce anaesthesia and secure the airway by tracheal intubation as quickly and smoothly as possible, while preventing regurgitation by external compression of the upper oesophagus.*

Rapid sequence induction is NOT a fast technique of inducing anaesthesia that allows surgery to start immediately. Properly conducted rapid sequence induction always takes a minute or two longer than induction in an elective, fasted patient. The added safety entirely justifies the extra minutes.

The recommended sequence is as follows:

- Aspirate the stomach contents with a large gastric tube; this helps decompress the stomach, but does not guarantee to empty it. Remove the tube before proceeding, as it makes the gastro-oesophageal sphincter leak.
- Set up a secure intravenous infusion.
- Pre-oxygenate the patient, and check that an efficient suction apparatus is within reach and turned on (put the end of the sucker under the pillow).
- Your assistant should now press firmly backwards with finger and thumb on the patient's cricoid cartilage (Fig. 8.1). This cartilage forms a complete ring around the trachea in front of the upper oesophagus, and will thus compress and occlude the oesophagus, making regurgitation of gastric contents into the pharynx unlikely. Cricoid pressure must be maintained until you have intubated the trachea, inflated the cuff, and tested it for leaks. *Make sure that your assistant understands this.*
- Once cricoid pressure has been applied, give the patient a previously calculated dose of thiopental by injecting it into the intravenous infusion tube, followed immediately by suxamethonium at 1 mg/kg of body weight.
- As soon as the patient relaxes, insert the laryngoscope and tracheal tube; inflate the cuff, test it for leaks, and tie the tube into position. A cuffed tube is not used in children aged less than 10 years, since the narrowest part of their airway is at the level of the cricoid cartilage, and a tube of the correct size will almost certainly fit this without the need for a cuff. If there is an air leak, pack the pharynx with moist ribbon gauze under direct vision using Magill's forceps. In children, it is especially important not to force in a tube that is too large, since the result will be oedema of the larynx after extubation. If a small leak of air round the tube during gentle inflation of the lungs can be heard, it is clear that the tube is not too tight. If, after intubation, you think that a smaller tube should have been used, change the tube immediately for a smaller one and little harm will have been done.
- Once the tube has been inserted and tested, ask your assistant to release the cricoid pressure.
- Even a cuffed tube cannot give absolute protection to the airway, so suck out any secretions from the mouth and pharynx before and after intubation and extubation.
- Once you have successfully intubated, you can proceed to any one of the possible anaesthetic plans outlined in Fig. 11.1, p. 105. It is wise to reinsert the

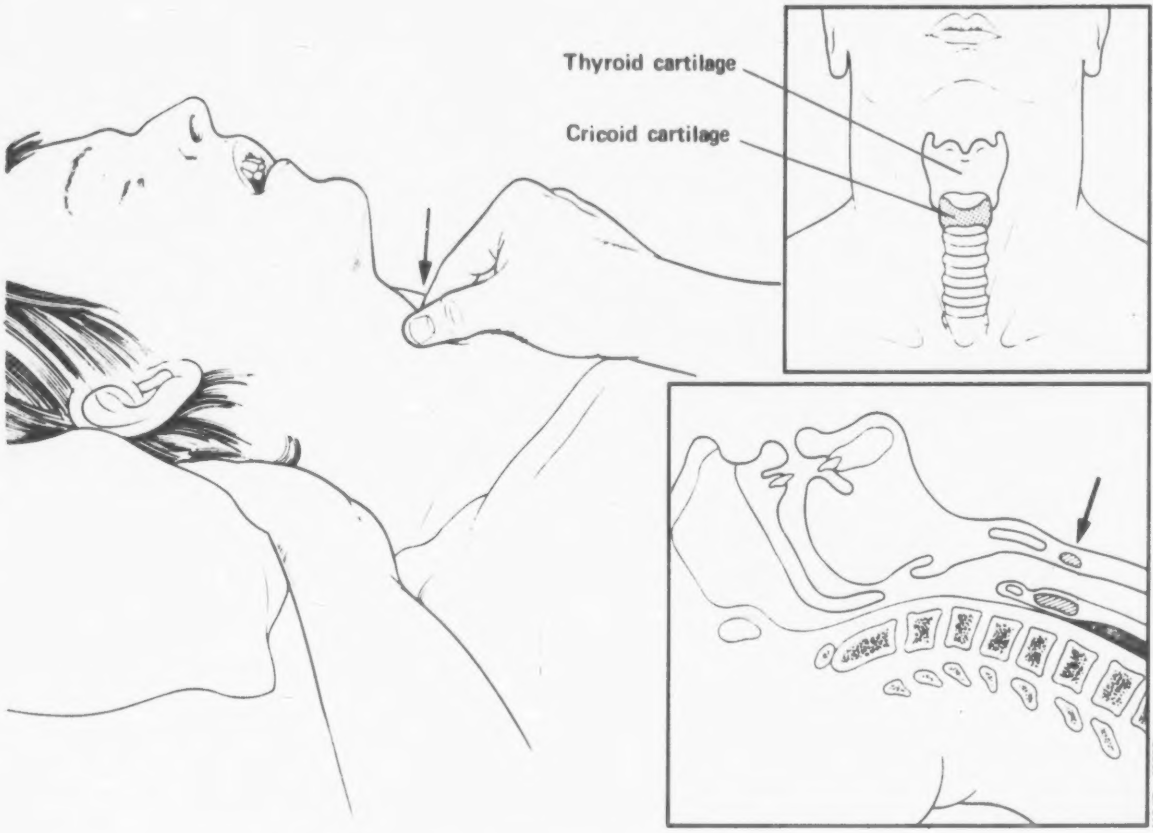


Fig. 8.1. Applying cricoid pressure to prevent regurgitation.

gastric tube and aspirate the stomach contents again. If the surgeon is operating in the abdomen, he or she can confirm that the tube has entered the stomach and can gently assist gastric emptying.

- Remember that at the end of the operation you must protect the patient's lungs by extubating with the patient awake and in the lateral position.

The rapid sequence induction described above is an important one with which both you and your assistant should be thoroughly familiar. It is harmless and not unpleasant for the patient, so you should practise it whenever possible on healthy patients for non-emergency operations to perfect your technique.

9
Drugs used in general anaesthesia

Inhalational agents

Diethyl ether
$(CH_3 \cdot CH_2 \cdot O \cdot CH_2 \cdot CH_3)$

Diethyl ether, commonly known simply as ether, is probably the most widely used inhalational agent in the world, because of its reputation (largely deserved) for safety, ready availability, and relatively low price. It is a colourless liquid with a strong, irritant smell and a boiling point of 35 °C. The concentrations used in anaesthesia vary from 2% to 15%. Ether is relatively soluble in blood, so the blood becomes saturated with the anaesthetic rather slowly; inhalational induction with ether is correspondingly slow, unless an additional agent such as halothane is used. Ether in anaesthetic concentrations is flammable when mixed with air and explosive when mixed with oxygen or nitrous oxide or both (see pp. 67–68). It should be stored in a cool, dark place.

Pharmacology

Ether has both anaesthetic and analgesic properties; the low concentrations that persist in the body after anaesthesia provide some relief from postoperative discomfort. During ether anaesthesia, there is an increase in catecholamine release from the adrenal glands, with an associated increase in cardiac output (except in very deep ether anaesthesia, when direct depression of the heart becomes more significant). Ether is safe to use when the surgeon wishes to infiltrate epinephrine or another vasoconstrictor drug. It produces muscle relaxation by an action similar to that of the non-depolarizing neuromuscular blocking drugs, whose effects it potentiates. It can be used as sole agent to produce sufficient muscular relaxation for laparotomy, though this requires deep anaesthesia, which results in slow postoperative recovery. Ether also produces some uterine relaxation in deep anaesthesia and may be used for external and internal version procedures in obstetrics. It is a bronchodilator and has been used to treat asthmatic attacks. When ether is given with a face mask, there is a marked increase in salivary secretion, which can be prevented by premedication with atropine. If secretions are profuse and are swallowed early in anaesthesia, the ether that has dissolved in them may cause gastric irritation and postoperative vomiting. There is certainly a higher incidence of postoperative nausea and vomiting after deep ether anaesthesia than after anaesthesia with other agents, but this is not the case after anaesthesia with a combination of 3% ether, a muscle relaxant, and IPPV, as described on pp. 74–75. Most (80–90%) of the ether that enters the body is exhaled again; the remainder is metabolized.

Anaesthesia with ether alone (including ether induction) produces the "classical" stages of anaesthesia:

Stage I — analgesia.

Stage II — confusion, dilated pupils, struggling, and the possibility of breath-holding and vomiting.

Stage III — surgical anaesthesia divided into planes 1–4 with a progressive increase in pupillary size; relaxation increases, starting with the abdominal and lower intercostal muscles and progressing upwards.

Stage IV — minimal diaphragmatic activity; blood pressure begins to fall; finally respiratory and cardiac arrest occurs.

It is rare to use ether unsupplemented in this way, because of the slow induction and recovery phases.

Halothane ($CF_3 \cdot CHClBr$)

Halothane is a halogenated hydrocarbon with a sweetish, non-irritant smell, which boils at 50 °C. The concentrations used in anaesthesia vary from 0.2 to 3%. It is a potent agent, and a calibrated vaporizer is necessary to avoid overdosage. Because it is less soluble in blood than ether, the blood becomes saturated more rapidly, so inhalational induction is relatively rapid and pleasant for the patient. If your supplies are limited, it is best to reserve halothane for facilitating inhalational induction or for settling a patient after intravenous induction, while you start giving ether. Halothane is neither flammable nor explosive in clinical conditions.

Pharmacology

Halothane produces a smooth induction of anaesthesia, but poor analgesia. Attempting to use it as sole agent for surgical anaesthesia can result in severe cardiorespiratory depression with marked cyanosis, unless the inspired gas contains a high concentration of oxygen. Halothane can produce some muscular relaxation, though less than ether. Like ether, it relaxes uterine muscle and is a bronchodilator. Depression of the respiratory centre by halothane usually produces shallow breathing at an increased rate; this increase in rate is less marked after opiate premedication. The main effect on the cardiovascular system is direct depression of the myocardium with a fall in cardiac output and blood pressure. However, there is marked skin vasodilatation, so the patient's tissues may appear well perfused. In a spontaneously breathing patient, the depressant effects on the heart are less marked than in a patient whose respiration is being assisted; in the former, retention of carbon dioxide (from respiratory depression) results in an increased secretion of catecholamines, whose cardiovascular effects tend to oppose the fall in cardiac output. Unfortunately, halothane also sensitizes the heart to the dysrhythmic effects of catecholamines, so dysrhythmias may occur. Surgical infiltration with epinephrine during halothane anaesthesia should therefore not be permitted.

Many of the disadvantages of halothane can be overcome by giving it in combination with an effective analgesic, and for this reason it has often been given in combination with nitrous oxide and oxygen.

Other volatile anaesthetic agents

Trichloroethylene has been widely used in the past, especially in a concentration of 0.5% as an analgesic supplement to other agents. Although its availability has recently diminished, it remains a useful and economical agent. Like halothane, it can cause dysrhythmias if the surgeon injects epinephrine, and its use should be avoided in these circumstances.

The volatile agents enflurane, isoflurane, sevoflurane, and desflurane are halogenated ethers. They offer some advantages as they are quickly eliminated from the body, and patients may be able to return home on the same day. Unfortunately, these agents are still very much more expensive than ether and halothane, and their availability is therefore limited. Like halothane, they are potent agents and should be given only from calibrated vaporizers.

Obsolete agents: chloroform, methoxyflurane, and ethyl chloride

Although chloroform, methoxyflurane, and ethyl chloride may still be available and in use in some parts of the world, they are extremely hazardous, particularly for the inexperienced anaesthetist, and their use cannot be recommended.

Intravenous anaesthetics

Thiopental (thiopentone)

Thiopental is a thiobarbiturate, i.e. a sulfur-containing barbiturate, presented as a yellow powder and used as a 2.5% aqueous solution for inducing anaesthesia. The solution is strongly alkaline and irritant, and hence problems may arise if it is injected outside the vein. Like all barbiturates, thiopental depresses cerebral function, producing unconsciousness together with depression of the respiratory and vasomotor centres. The respiratory and vasomotor depression is relatively transient and mild in healthy patients given a sleep dose, but an overdose can cause hypotension or respiratory arrest. After a normal induction dose, anaesthesia is produced in one arm–brain circulation time — usually 15–25 s, but longer in elderly or hypovolaemic patients. Typically, the patient takes a deep breath or sighs just before losing consciousness. If a single dose is given, the patient will remain unconscious for about 7 min, but may react to painful stimulation towards the end of this time.

Recovery occurs because the drug passes out of the brain, where it is initially concentrated, into other tissues. Although barbiturates are eventually broken down in the liver, this takes several hours. Consequently, if repeated doses of thiopental are given, there will come a point where all the body's stores have become saturated, and the patient may then take many hours or even days to recover consciousness. Repeated doses of thiopental should therefore not be given to prolong anaesthesia. For a short procedure lasting only a minute or two, it is possible to use a single dose of thiopental as the sole anaesthetic, but beware of laryngeal spasm if the procedure is painful or causes vagal stimulation — for example anal or cervical dilatation.

Methohexital (methohexitone)

Methohexital is sometimes available as an alternative to thiopental. It is more potent, the powder being diluted to make a 1% solution, with an average sleep dose of 1 mg/kg of body weight. After a single dose, patients wake up more quickly than after thiopental, but there is still an element of "barbiturate hangover", and no patient who has been given either drug should drive a vehicle, operate machinery, or drink alcohol during the following 24 hours.

Ketamine

Ketamine is a unique drug. In anaesthetic doses, it produces a trance-like state of "dissociative anaesthesia", which consists of profound analgesia with only slightly impaired pharyngeal and laryngeal reflexes. There is sympathetic activation, with mild cardiovascular stimulation and small increases in arterial blood pressure, and also increases in intracranial and intraocular pressures. Like ether, ketamine is a bronchodilator, and when given in large doses by the intramuscular route, it produces profuse salivation, so atropine is usually given before or with it. It is oxytocic and should therefore not be given during pregnancy, except at term for forceps delivery or caesarean section. It does not provide any muscular relaxation; indeed the patient's limbs sometimes become fixed in abnormal positions because of altered muscle tone. The induction dose generally recommended is 1–2 mg/kg of body weight given intravenously (depending on premedication) or 6–8 mg/kg given intramuscularly. Several formulations of different strengths are available, but it is recommended that the 50 mg/ml strength be used as the standard, and diluted if required for intravenous use. The formulation of this strength is presented as a multidose ampoule, which should be refrigerated after opening.

For procedures requiring relaxation and also for more general use, ketamine can be given by infusion in conjunction with a muscle relaxant and IPPV with air. Ketamine provides light surgical anaesthesia in much the same way as 3% ether. Infusing the drug reduces the total dose needed and allows more rapid recovery. The average infusion rate used for an adult is about 1 mg/min.

In subanaesthetic doses of around 0.5 mg/kg of body weight, ketamine is an excellent analgesic and produces no clinical evidence of respiratory depression. It is particularly valuable for providing analgesia when it is necessary to move a patient with a painful lesion, for example to position a patient for conduction anaesthesia or to change a plaster or dressing. Ketamine has also found a special place as an anaesthetic for children in whom repeated anaesthesia is needed over a short period and when access to the airway may be difficult. No anaesthetic can guarantee a safe airway, but the airway is certainly less at risk during ketamine anaesthesia than with any other general anaesthetic technique. In a patient with a family history of malignant hyperthermia, ketamine may be safely used.

Ketamine's main drawbacks are its relatively high cost and limited availability. Hallucinations during recovery may be a problem (though rarely so in children), but do not occur if ketamine is used as an induction agent only and is followed by a conventional inhalational anaesthetic. The incidence of hallucinations after ketamine is given as the sole anaesthetic agent can be reduced by suitable sedative premedication with a benzodiazepine or butyrophenone drug. The formulation of ketamine normally available is a mixture of two optical isomers (referred to as (+) and (−)). Of these, the (+) isomer has more anaesthetic potency and much less tendency to produce dreaming. If the purified (+) isomer becomes widely available in future it will represent a considerable improvement.

Benzodiazepines

Benzodiazepines (diazepam, temazepam, nitrazepam, midazolam etc.) given orally are widely used for sedation and relief of anxiety. They also produce amnesia, and in the elderly may cause confusion. Some members of the group, e.g. diazepam, are metabolized to other substances that are themselves sedative and depressant for a prolonged period. More recently introduced drugs such as temazepam and midazolam do not suffer from this disadvantage.

Intravenous administration of benzodiazepines produces a rapid onset of sedation, and unless great care is used, this can rapidly progress to a state indistinguishable from general anaesthesia with loss of airway control, respiratory depression, and hypotension. The use of intravenous benzodiazepines for "sedation" by untrained personnel should not be permitted. Another misuse of these drugs is to give them to "settle" a patient in severe pain; they have no analgesic effect and should not be used in this way.

Intravenous injection of diazepam or midazolam can be used for induction of anaesthesia. Both onset and recovery are slower than with other intravenous induction agents. The common formulation of diazepam (dissolved in ethylene glycol) causes severe pain on intravenous injection, often followed by severe thrombophlebitis. This is not a problem with the diazepam emulsions, or with midazolam which is a water-soluble preparation.

Benzodiazepine overdose can be reversed with the specific antagonist flumazenil, but the action of the antagonist is much shorter than that of the benzodiazepine, and the patient may lapse into drowsiness or unconsciousness a few minutes later.

Opiate drugs

Opiate analgesics such as morphine (natural) and pethidine (synthetic) are sometimes used in premedication. They are also of value in preventing reflex responses to painful stimulation during anaesthesia (shown in the paralysed patient by tachycardia, sweating, or a rise in blood pressure), particularly when light general anaesthesia with nitrous oxide is being used. (Analgesic supplements are rarely needed during ether anaesthesia.) As a supplement to anaesthesia, give small doses of opiate drugs intravenously (for example morphine 0.1 mg/kg or pethidine 0.25 mg/kg of body weight). Do not give increments of opiate in the last half-hour of surgery or you may have trouble getting the patient to start breathing again. Opiates depress respiration, usually by reducing the respiratory rate, with little effect on the depth of respiration. In the postoperative period, it is advisable to give at least the first dose of opiate analgesic intravenously, as the patient's responses, in terms of both analgesia and possible respiratory depression, can be closely watched and the dosage adjusted to the patient's needs more easily than if the drug is given intramuscularly.

Severely injured patients who require opiate analgesics should receive them only by the intravenous route, since absorption from other sites may be delayed because of poor perfusion. For example, an opiate drug injected intramuscularly may not produce adequate analgesia and a further dose may be given; when the circulation is restored and hence the perfusion of the injection site improved, all the drug will be absorbed at once, which may cause a collapse from opiate overdose.

Opiate overdose and antagonists

If an overdose of opiate is accidentally given, the main problem is likely to be respiratory depression. Primary treatment must always consist of artificial ventilation if necessary, using whatever apparatus is available. Naloxone is a specific opiate antagonist that can be given intravenously or intramuscularly and is capable of completely reversing the depressant effects of opiates. Its effects are briefer than those of morphine, particularly if it is given intravenously, and supplementary doses, preferably intramuscular, are recommended to prevent the return of the effects of morphine. Nalorphine is a cheaper alternative to naloxone, but it can produce respiratory depression in its own right if an overdose is given, so more care is needed.

Non-steroidal anti-inflammatory drugs (NSAIDs)

These drugs, used for many years to control the pain of arthritis, have found an increasing role in the management of postoperative pain — either used alone, or in combination with opiate analgesics, in which case the dose (and side-effects) of the opiates can usually be reduced. Care is needed because non-steroidal anti-inflammatory drugs can themselves have serious side-effects, including impairment of platelet function and renal failure in susceptible patients (especially patients with poor cardiovascular function, elderly patients, and patients in shock).

Muscle relaxant drugs

These are drugs that act at the neuromuscular junction, blocking transmission of nerve impulses and causing muscular relaxation and paralysis. They have no effect on consciousness or sensation, so you must never give them to a conscious patient, or to any other patient unless you are sure that you can ventilate the lungs with a face mask and also pass a tracheal tube. Muscle relaxation during anaesthesia is required:

- to allow laryngoscopy and intubation during light anaesthesia
- to improve the surgeon's access to specific organs and tissues.

Physiology of neuromuscular transmission

When a motor nerve is stimulated, a wave of electrical depolarization passes along it as far as the nerve ending on the muscle (the motor end-plate). At this point the arrival of the electrical impulse triggers the release of a stored chemical transmitter, acetylcholine, which diffuses across the synaptic cleft and stimulates the muscle receptors, producing electrical depolarization, and mechanical contraction of the muscle fibre. The acetylcholine is then broken down by an enzyme (acetylcholinesterase) or taken up again by the nerve ending.

Muscle relaxants resemble molecules of acetylcholine closely enough to bind to its receptors, but their effect differs from that of acetylcholine.

Suxamethonium (succinylcholine)

Suxamethonium actually consists of two acetylcholine molecules joined together. It causes depolarization of the muscle fibres, which can be seen as a fine twitching (fasciculation) of all the muscles after an intravenous dose of 1 mg/kg of body weight, followed by profound relaxation, usually within 45 s of injecting the drug. After this initial action, the motor end-plates remain depolarized and the muscles therefore paralysed until the suxamethonium is broken down by the enzyme plasma (nonspecific) cholinesterase, usually after 3–5 min. A few people have abnormal plasma cholinesterase, and the action of suxamethonium may then last for hours or even days, during which time IPPV must continue without a break to allow the patient to survive. If treated in this way, the patient should eventually make a full recovery. No specific agent is available for reversing the action of suxamethonium.

If given in repeated doses, suxamethonium may cause bradycardia, and atropine should be given to prevent this. In patients with extensive tissue damage, for example a crush injury or severe burn, suxamethonium may lead to a massive loss of potassium ions from cells into the circulation and it is therefore contraindicated in such cases.

The commonest formulation of the drug is as liquid suxamethonium chloride in ampoules, but these must be kept between 0 and 20 °C during transportation and storage or activity will be lost. Powdered, heat-stable formulations of suxamethonium salts are available from a number of manufacturers. The bromide is slightly more potent than the chloride.

Non-depolarizing relaxants

These drugs block the acetylcholine receptors on the muscle but do not depolarize the muscle membrane. Their duration of action is usually around 30 min, which is longer than that of suxamethonium, and the onset is rather slower — up to 3 min for a full effect. An initial loading dose is normally followed by smaller increments, which maintain relaxation during surgery.

Neostigmine is used to antagonize the residual effect of non-depolarizing relaxants at the end of surgery. It is an acetylcholinesterase inhibitor and therefore causes an increase in the concentration of acetylcholine at the nerve endings. This acetylcholine antagonizes the muscle relaxant effects by competing with the relaxant drug for access to the receptors. If used alone, neostigmine would cause severe bradycardia (even cardiac arrest) and the production of copious secretions as a result of cholinergic stimulation of vagus nerve endings. It must therefore be given only with or immediately after atropine injected intravenously. Normal doses are atropine 0.02 mg/kg of body weight and neostigmine 0.04 mg/kg. The actions of non-depolarizing relaxants can be successfully reversed only after the effects have begun to wear off — at least 15 min after the last dose is given.

Many different non-depolarizing relaxants are available, but their actions are all basically similar. Those commonly available are gallamine, alcuronium, vecuronium, pancuronium, and tubocurarine.

Gallamine is widely used, and tends to produce a tachycardia by a vagolytic effect. Its excretion is entirely by the kidney, so it must not be given to patients with renal failure. The usual dose is 1–1.5 mg/kg of body weight, with increments of 0.5 mg/kg.

Other non-depolarizing relaxants may be used if available. Tubocurarine is fairly expensive but is the established favourite of many; it causes marked histamine release and tends to reduce blood pressure. Pancuronium is a potent synthetic agent that has little effect on blood pressure, but it requires refrigerated transportation and storage, as does atracurium. Vecuronium is an excellent relaxant with few adverse effects, which is formulated as a heat-stable powder with a long shelf-life. Unfortunately in many places it remains expensive.

Guidelines and warnings for the use of relaxants

- Never give a relaxant to a patient whose airway may be difficult to manage.
- Always allow the effects of suxamethonium to wear off before giving a dose of another relaxant.
- Never attempt to reverse the effects of a non-depolarizing relaxant before evidence of a return of muscle tone or breathing in the patient.
- Always give reversal agents if non-depolarizing relaxants have been used, even if their effects seem to have worn off.
- Always remember that a relaxant is not an anaesthetic; check that you are keeping the patient properly asleep, and not merely paralysed, awake, terrified, and in agony.
- *Before extubation* your patient must:
  - — be capable of sustained muscular contraction, for example raising the head or limbs;
  - — be turned into the lateral position (unless there is a specific reason for not doing so).

10

Conduction anaesthesia

General anaesthesia relies on the action of drugs within the central nervous system to produce unconsciousness and depress responses to painful stimulation. Techniques of conduction (regional) anaesthesia use locally acting drugs to block nerve impulses before they reach the central nervous system.

Local anaesthetic drugs depress the electrical excitability of tissues (hence also their use to treat cardiac dysrhythmias). When injected close to nerves they block the passage of the depolarization wave necessary for the transmission of nerve impulses. The slenderest fibres (which carry the sensations of pain and temperature, and also efferent sympathetic impulses) are blocked first, those carrying touch and proprioception impulses next, and motor fibres (which control muscle tone as well as voluntary movement) last of all. A high concentration of drug will block all sensation and movement, while a low concentration will block only pain sensation, producing a "differential block". Differential block can almost always be observed during the onset and recovery periods of a successful block — the sensations of pinprick and temperature disappear first and are regained last. The onset of a successful block is often shown by the vasodilatation resulting from sympathetic blockade.

Toxicity and safety of local anaesthetic drugs

All local anaesthetic drugs are potentially toxic and may depress the central nervous system and cause drowsiness, which may progress to unconsciousness with twitching and possibly convulsions. There may be hypotension related either to extensive sympathetic blockade, for example after "high" spinal anaesthesia, or to direct depression of cardiac function from high blood levels of the drug. These reactions are most likely to occur if the drug is accidentally injected into a vein or if an overdose is given by using either too high a concentration or too large a volume of drug. Toxic effects — usually cardiac dysrhythmias — may also occur after intravascular injection or rapid absorption of a vasoconstrictor drug such as epinephrine, which is frequently mixed with local anaesthetic to prolong the latter's action. Occasionally, patients have a true allergic reaction to the local anaesthetic drug, but this is unusual.

If a severe toxic reaction occurs, prompt resuscitation is needed: give oxygen and IPPV if there is severe respiratory depression. Convulsions, when associated with hypoxia, are best treated initially by giving a dose of suxamethonium and ventilating the lungs. If the convulsions persist, you may need to give anticonvulsant drugs such as diazepam or thiopental intravenously, but they should not be given as first-line treatment to a patient who may be hypotensive. It follows from the above that *full facilities for resuscitation should be available whenever you use conduction anaesthesia*, just as they should when you use general anaesthesia.

Table 5. Maximum safe doses of local anaesthetic drugs

Drug	Maximum dose (mg/kg of body weight)	Maximum dose (ml) for 60-kg adult
Lidocaine 1%	4	24
Prilocaine 1%	6	36
Lidocaine 1% + epinephrine 5 μg/ml (1:200000)	7	42
Bupivacaine 0.25%	1.5	36
Bupivacaine 0.25% + epinephrine 5 μg/ml (1:200000)	2	48

Safe and toxic doses

As with all drugs, the maximum safe dose is related to the size and condition of the patient. Blood levels (which reflect systemic absorption) tend to be higher when more concentrated solutions are used; for example, 5 ml of a 2% lidocaine solution (20 mg/ml) will produce higher blood levels than 10 ml of a 1% solution. Avoid toxicity by using the most dilute solution that will do the job, for example 1% lidocaine or 0.25% bupivacaine for most nerve blocks and 0.5% lidocaine or prilocaine for simple infiltration. The rate of absorption of the drug can also be reduced by injecting it together with a vasoconstrictor drug such as epinephrine, which is most often used in a dilution of 5 μg/ml (1:200000); for infiltration, 2.5 μg/ml (1:400000) is enough. Pre-mixed ampoules of local anaesthetic and epinephrine are often available, but if not, you can easily make a 5 μg/ml dilution by adding 0.1 ml of a 0.1% epinephrine solution (1:1000 epinephrine) to 20 ml of local anaesthetic solution. The addition of epinephrine has two useful effects: it reduces the rate at which local anaesthetic is absorbed from the injection site (by causing vasoconstriction) and therefore allows a larger dose of local anaesthetic to be used without toxic effects; at the same time, since local anaesthetic is removed from the injection site more slowly, the duration of anaesthesia increases by up to 50%. Epinephrine and other vasoconstrictor drugs must never be used for parts of the body that do not have a collateral circulation (ears, fingers, toes, and penis) as they could produce ischaemic damage, nor of course should they be used for intravenous regional anaesthesia. When injecting local anaesthetic use a small gauge needle — 21–23 gauge for nerve blocks and 23–25 gauge for infiltration. This reduces the risk of toxicity — it is all too easy to inject an excessive dose through a large-bore needle.

The maximum safe doses of various local anaesthetic drugs are shown in Table 5.

Note that for a 3-kg infant the toxic dose of 1% lidocaine is only 1.2 ml.

Contraindications to conduction anaesthesia

It is a common misconception that general anaesthesia is more dangerous than conduction anaesthesia. In fact, for major surgery, there is no evidence of any difference in morbidity and mortality between patients undergoing good-quality general anaesthesia and those undergoing conduction anaesthesia. Certain specific contraindications to conduction anaesthesia exist, including the following:

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- true allergy to local anaesthetic drugs
- sepsis at the intended site of injection
- inability to guarantee sterile equipment for injection
- systemic treatment of the patient with anticoagulant drugs (though local infiltration of a local anaesthetic drug on a small scale is permissible).

Other, but not absolute, contraindications include reluctance of the patient to undergo conduction anaesthesia, "difficult" sites of operation, and prolonged surgical procedures. In many cases, these last difficulties can be overcome by combining conduction anaesthesia with intravenous sedation or with light general anaesthesia.

General precautions and basic equipment

Before beginning any form of conduction anaesthesia, you should:

- ensure that the patient has been properly prepared and fasted as for general anaesthesia, which may become necessary if the conduction anaesthesia is unsuccessful;
- ensure that apparatus for resuscitation is at hand in case there is an adverse reaction;
- insert an indwelling needle or cannula and, for major operations, set up an intravenous infusion of an appropriate fluid.

Sedation during conduction anaesthesia

Patients undergoing surgery under conduction anaesthesia often need some sedation to reduce anxiety or to help them to lie still. This is best achieved by oral premedication — drugs taken orally are safer and cheaper. Sometimes a small additional dose of intravenous sedative can be necessary, but do not use this to "cover up" an inadequate conduction technique, and do not let "sedation" drift into unconsciousness with an uncontrolled airway.

Specimen techniques

Practical conduction anaesthesia cannot be learned from a book, but only by working with an experienced practitioner.

There are many hundreds of individual conduction anaesthetic techniques and few anaesthetists would claim to be expert in all of them. The specimen techniques described here are intended as a reminder of the important aspects of a few useful techniques that should have already been demonstrated for you. Epidural anaesthetic techniques have been deliberately left out since they generally require more skill and experience, are more difficult, take longer to perform, and are less predictable in their effects than the alternative, which is usually a (subarachnoid) spinal anaesthetic technique.

In the description of each technique it is assumed that the site of injection has been thoroughly cleaned and then prepared with a bactericidal antiseptic.

Topical anaesthesia of mucous membranes

This can be performed very simply by applying 4% lidocaine (or 5% cocaine if available) to the mucous membrane. It is suitable for instrumentation and minor operations on the nose, and superficial surgical procedures on the eye. Topical anaesthesia of the mouth, pharynx, and larynx is also possible and is one of the methods recommended for use in a patient whose airway is or may be difficult to manage, but do not anaesthetize the larynx if the stomach is full, as this will remove the patient's protective reflexes and make regurgitation likely. The simplest way to anaesthetize the larynx is to insert a 21-gauge needle through the

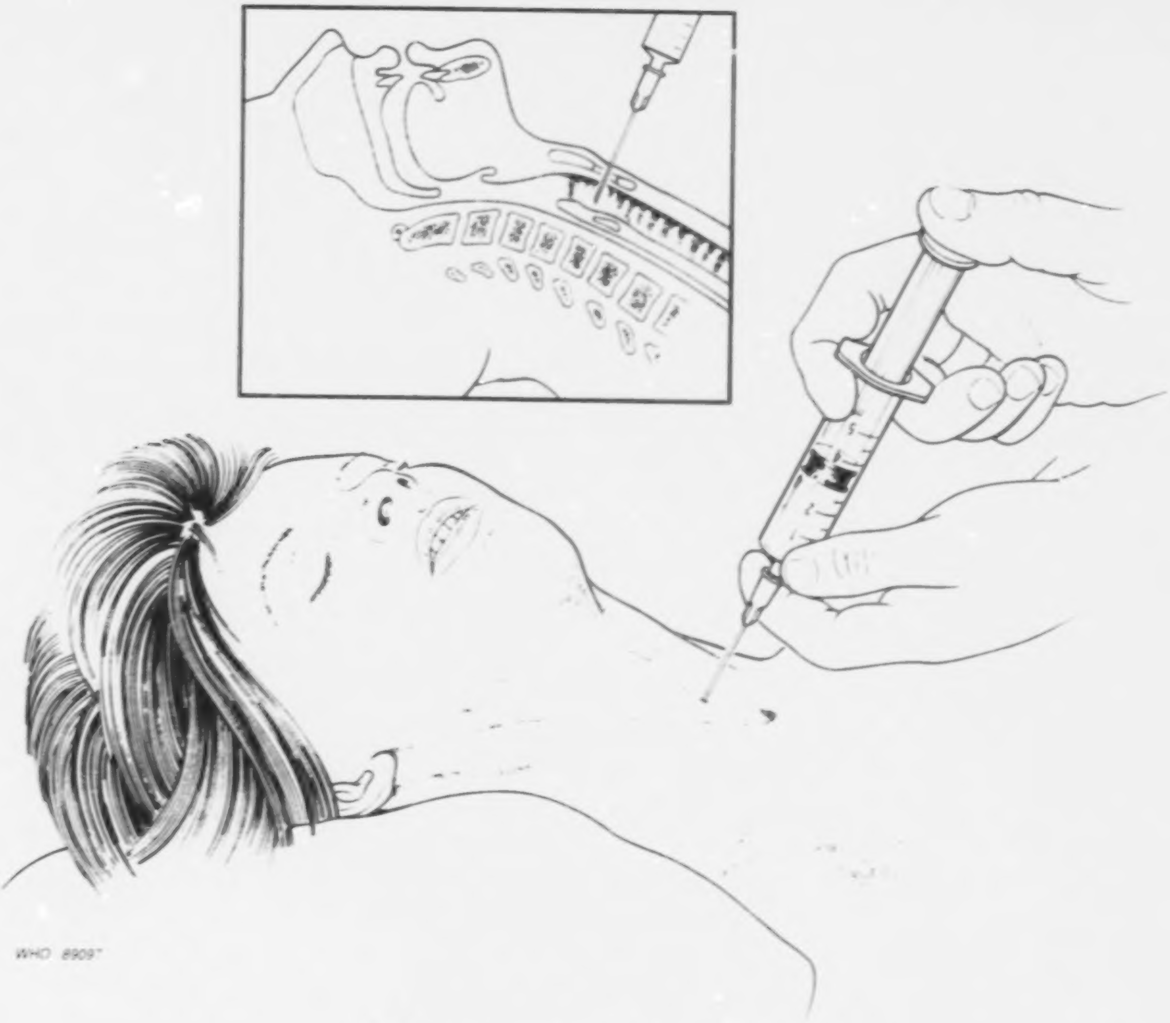

Fig. 10.1. Local anaesthesia of the larynx by cricothyroid injection

cricothyroid membrane into the lumen of the trachea, where you should be able to aspirate air freely (Fig. 10.1), then rapidly inject 3 ml of 4% lidocaine, and remove the needle instantly (the patient will cough). Spray the throat with another 2 ml of 4% lidocaine, and after a few minutes laryngoscopy and intubation will be possible. Extreme gentleness and a gradual approach are necessary.

Simple infiltration

For infiltration you will need a sterile syringe with a fine (23-gauge or smaller) needle and lidocaine 0.5% with epinephrine 5 μg/ml (1:200 000) or, if a large volume is needed, lidocaine 0.375% with epinephrine 3.3 μg/ml (1:300 000). If necessary, you can use up to 120 ml of the weaker concentration in a normal 65-kg adult.

For suturing a wound, after skin preparation with antiseptic, inject the local anaesthetic solution superficially (where most of the nerve endings are) about 5 mm from the margins of the wound, and allow about 5 min for the block to take effect.

Field blocks

The principle of a field block is to lay down a "barrage" of local anaesthetic to block all the sensory nerves that supply the operation site. It is particularly useful for areas where the nerve supply is both complex and variable, the groin for example, and can also be used for caesarean section if other methods of anaesthesia are not possible.

For repair of an inguinal hernia

Lidocaine 1.0% with epinephrine 5μg/ml (1:200000) is used for this block. From a point two fingers' breadth from the anterior superior iliac spine, infiltrate the muscles in front of the pelvis with 5ml of solution (Fig. 10.2A). Use a long, fine needle to avoid multiple punctures, and keep the point of the needle moving during injection to avoid accidentally injecting a significant amount into any vessel. From the same point, inject 5ml medially under the external oblique aponeurosis, directing the point of the needle towards the midline (Fig. 10.2B). From a second injection point above the pubic tubercle, infiltrate 5ml under the

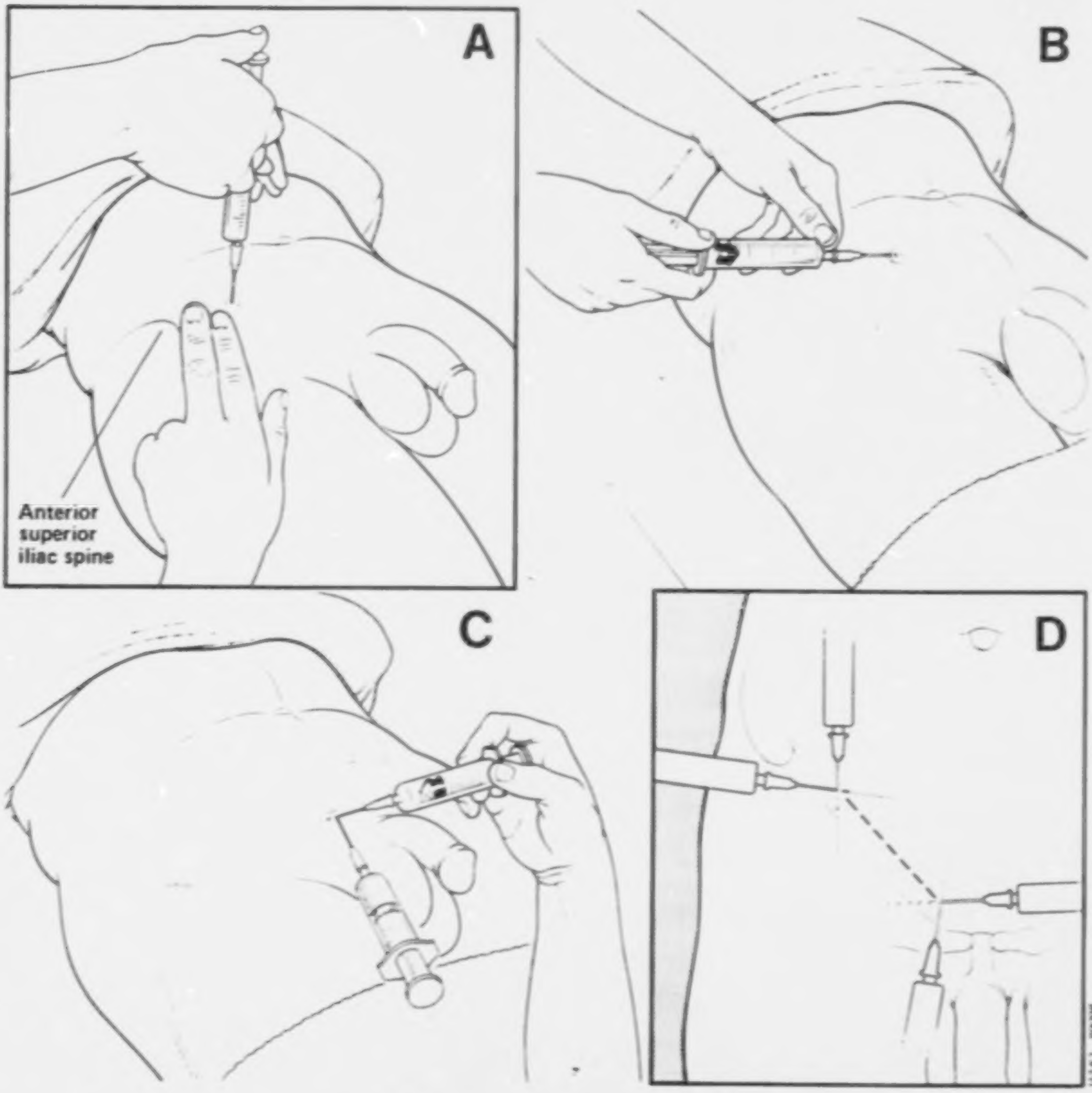

Fig. 10.2. Stages in performing an inguinal field block.

external oblique aponeurosis with the needle directed towards the umbilicus and another 5 ml in the same plane in a lateral direction (Fig. 10.2C). Finally, inject about 5 ml "fanwise" in the subcutaneous plane from each end of the planned line of the incision (Fig. 10.2D). If the hernia is reducible, inject 5 ml more into the superficial inguinal ring at the midpoint of the inguinal ligament. If necessary, further injection can be made by the surgeon into the deeper tissues during the operation. Field block does not of course anaesthetize any bowel or intraperitoneal tissue, which the surgeon must therefore handle gently.

For caesarean section

A long wheal of local anaesthetic solution is raised 3–4 cm either side of the midline from the symphysis pubis to a point 5 cm above the umbilicus (Fig. 10.3). Infiltrate the solution down through the layers of the abdominal wall using a long needle, which should remain almost parallel to the skin. Be careful not to pierce the peritoneum and insert the needle into the uterus, as the abdominal wall is very thin at term. Up to 100 ml of 0.5% lidocaine with epinephrine 5 µg/ml (1:200 000) may be used. The procedure may be uncomfortable for the mother, but analgesics and sedatives must not be given intravenously or the baby's physiological functions will be depressed. If necessary, up to 0.5 ml/kg of body weight of ketamine can be given intravenously to provide maternal analgesia without risk of depressing the baby. Once the baby is delivered, you can of course give opiates intravenously to the mother if needed. It is always advantageous to give additional oxygen to the mother during a caesarean section.

For circumcision

This technique is useful either for surgery or to provide postoperative analgesia following administration of a general anaesthetic. Inject a ring of local anaesthetic (without epinephrine) subcutaneously and intradermally around the base of the penis; block each dorsal nerve by an injection of 5 ml into the dorsum of the penis, with the needle resting against the corpus cavernosum (Fig. 10.4A). Block the para-urethral branches by injecting ventrally, with the penis pulled up, into the grooves between the corpora cavernosum and spongiosum (Fig. 10.4B, C, D).

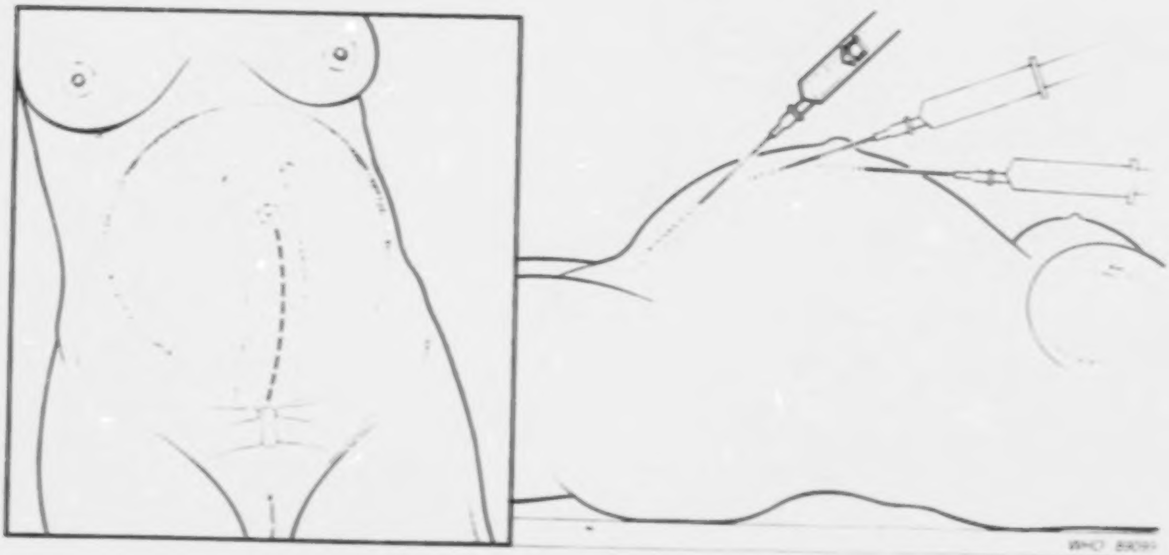

Fig. 10.3. Field block for caesarean section

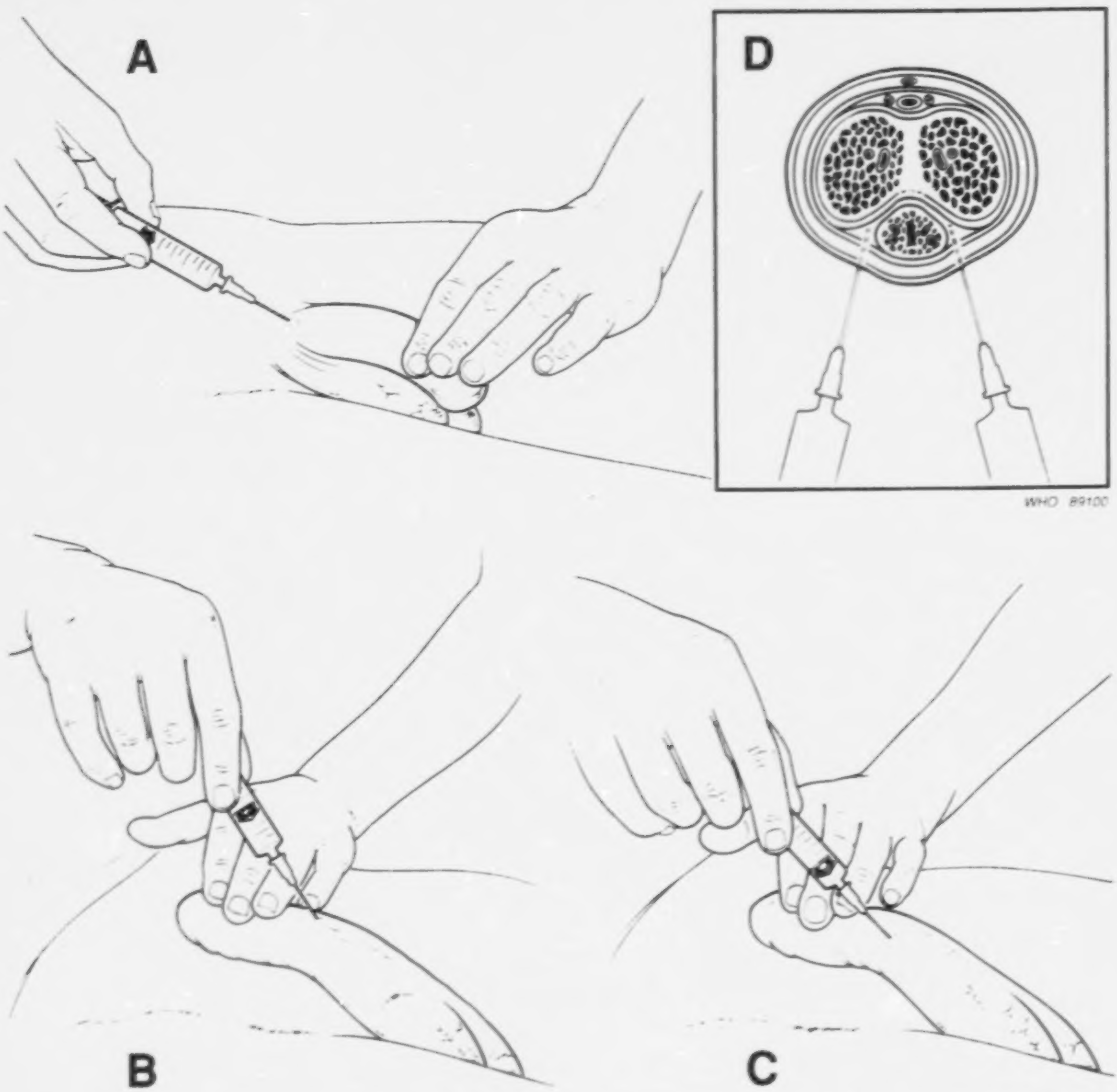

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Fig. 10.4. **Field block for circumcision.** (A) Injection to block the dorsal nerves; (B, C, D) injection to block the para-urethral branches.

Nerve block techniques

The aim here is to deposit local anaesthetic next to a specified nerve and block sensation from the area that it serves. The concentration of anaesthetic used (1% lidocaine or occasionally 1.5–2%) is slightly higher than for field block, because in a nerve block the drug may have to diffuse through a thick fibrous sheath to reach the nerve.

Digital nerve block (ring block)

Each finger and toe is supplied by two dorsal and two palmar or plantar branches of the digital nerve, which can be simply blocked by a ring of local anaesthetic injected at the base of the digit (Fig. 10.5). A tourniquet is applied to localize the anaesthetic and to minimize bleeding. Do not use more than 4 ml of solution (1% lidocaine) per digit, or the tissues may be damaged by the high pressure developed. *Epinephrine must never be used in ring blocks.*

Nerve block at the ankle

Three separate injections are needed for this useful block, so it is kind to give the patient some basal sedation or analgesia or both. The anterior tibial nerve is

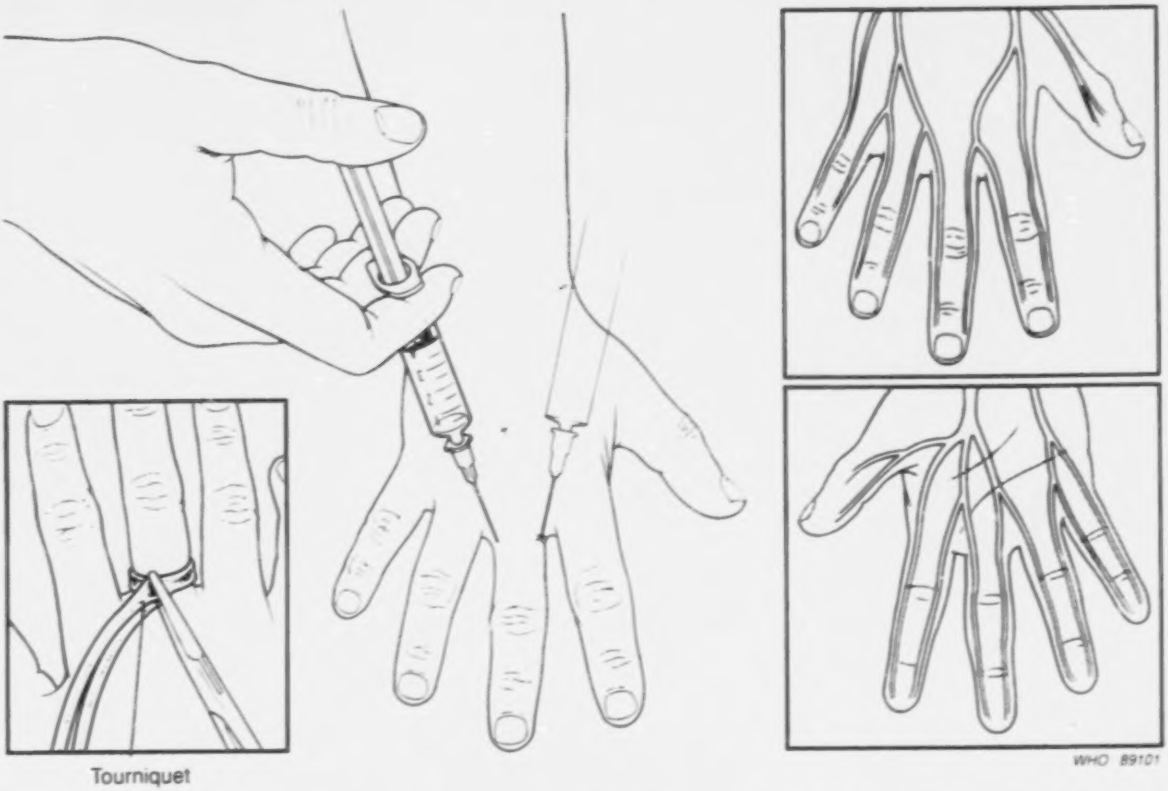

Fig. 10.5. Digital nerve block: injection at the base of the digit to block the dorsal and palmar branches of the nerve. (This block can also be used for the toes.)

first anaesthetized with 2–3 ml of 1% lidocaine injected on the anterior surface of the tibia at a point midway between the malleoli (Fig. 10.6A). The posterior tibial nerve is then blocked by an injection midway between the medial malleolus and the Achilles tendon: advance the needle perpendicular to the skin until bone is contacted; then withdraw slightly and inject 2 ml of 1% lidocaine (Fig. 10.6B). Thirdly, block the terminal branches of the saphenous and sural nerves by subcutaneous infiltration of up to 10 ml of solution along a line joining the malleoli around the front of the ankle (Fig. 10.6C, D).

Axillary block of the brachial plexus

The lower part of the brachial plexus is contained within a fibrous sheath, which also carries the axillary artery and vein. The nerve tissue is in three bundles, or cords, described as medial, posterior, and lateral in relation to the artery. Injection of local anaesthetic into this sheath is capable of producing conduction anaesthesia of the upper limb (except for the area innervated by the musculocutaneous nerve, which leaves the main nerve bundle rather high in the axilla). When performed successfully, this block allows surgery on most of the upper limb, and the use of a tourniquet when required.

Ask the patient to lie supine with the arm to be anaesthetized positioned to produce 90 degrees of abduction and external rotation (a suitable position is with the patient's hand under his or her head). Palpate the axillary artery and, after skin preparation, insert a short needle just above or below the artery (Fig. 10.7). You may feel the needle enter the sheath, and the patient may report tingling in the arm. When the needle is correctly placed (do not attach the syringe yet), you will see it move with every pulsation of the artery. If you insert the needle into the artery or vein by accident, remove it and apply firm pressure for 3 min; provided that a haematoma does not occur, you can then make another attempt.

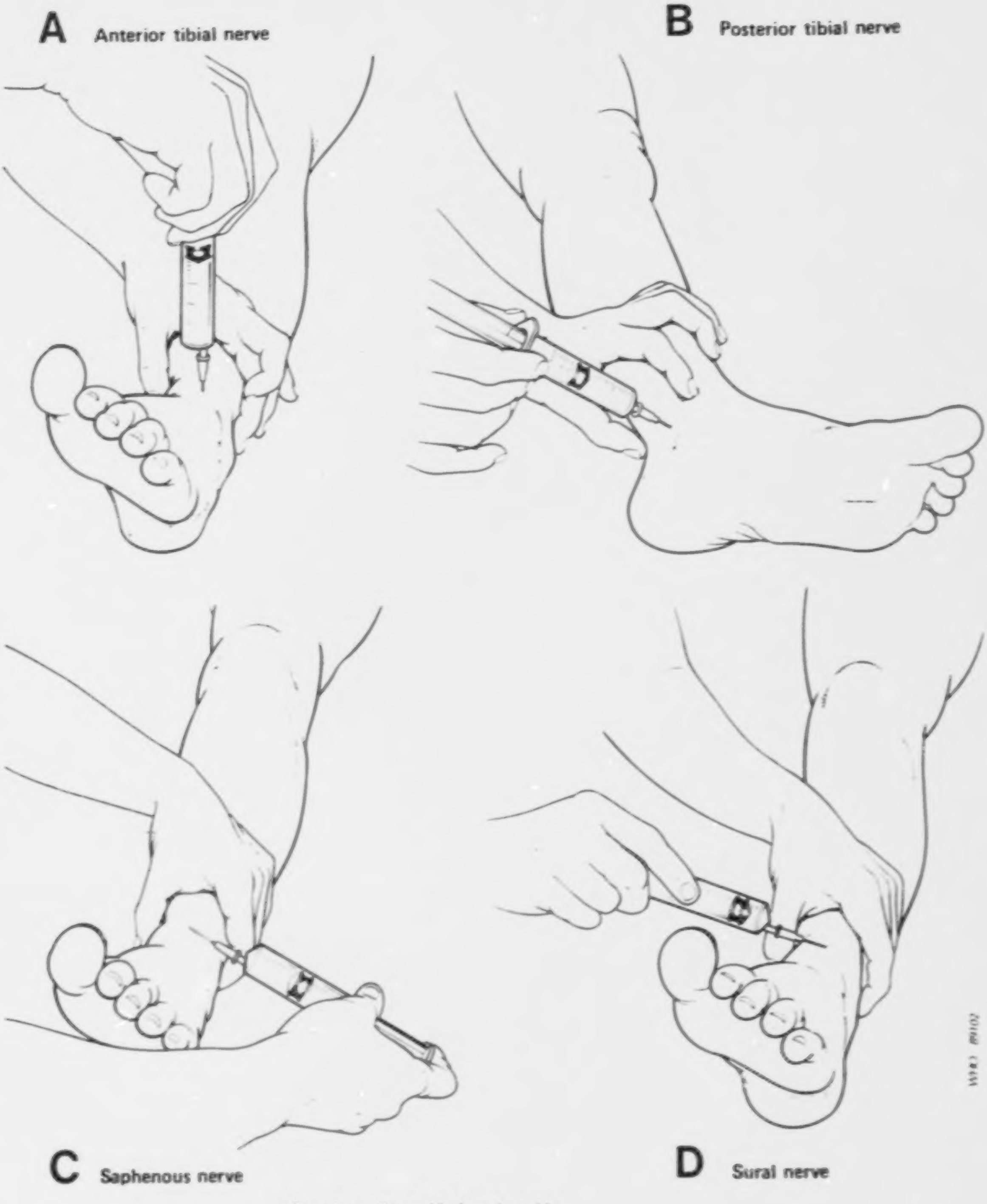
A
Anterior tibial nerve
B
Posterior tibial nerve
C
Saphenous nerve
D
Sural nerve
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Fig. 12.6. Nerve block at the ankle

Once the needle is correctly placed, connect the syringe and inject 30 ml of 1% lidocaine with epinephrine. You must be absolutely certain before you do this that the needle is not in a vessel. If your needle is correctly placed, the patient may again report tingling. A correctly placed injection does not cause a large swelling, as the local anaesthetic solution is carried upwards in the sheath towards the neck. During injection, your assistant should press firmly on the artery about

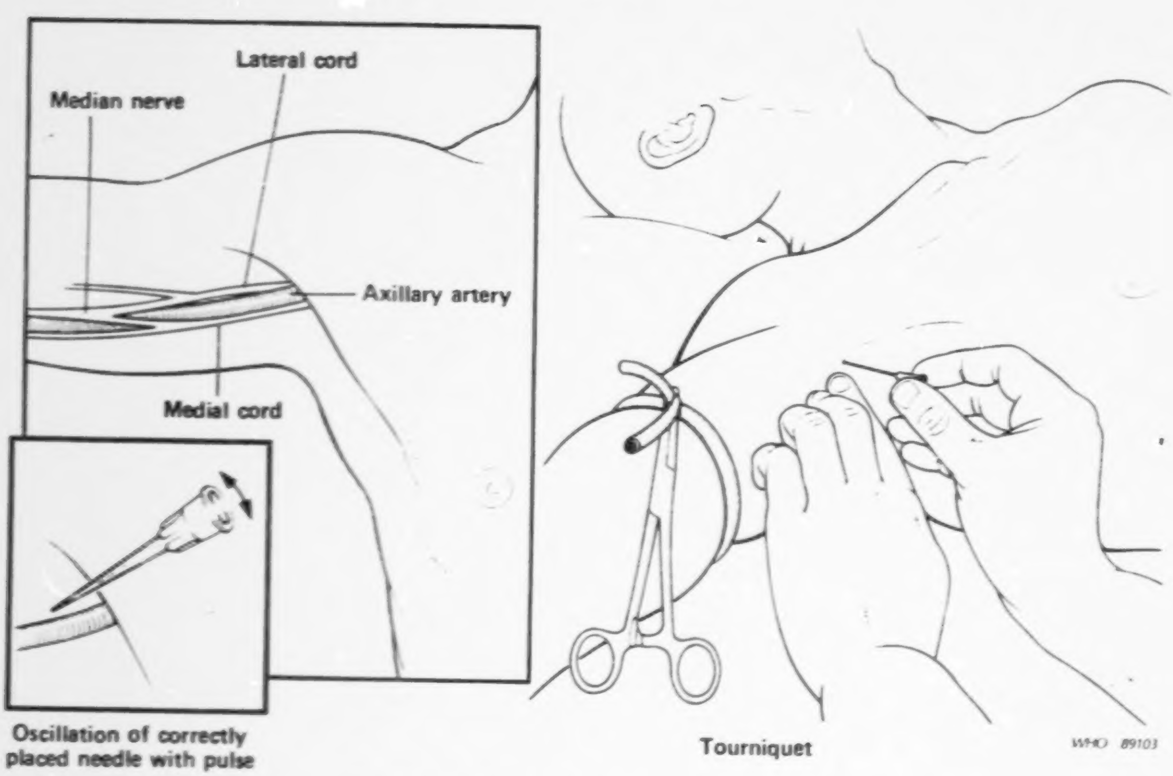

Fig. 10.7. Axillary block of the brachial plexus.

3 cm below the point of injection to compress the sheath and prevent local anaesthetic from passing down the arm, where it would be wasted.

As an alternative to digital pressure, some anaesthetists prefer to apply a light tourniquet below the injection site. The commonest mistake with this block is to inject too deeply; the sheath is superficial in position, often only 2–3 mm from the skin. After injection, the block develops slowly and may take up to 30 min to become effective. If bupivacaine has been used, the block can last for up to 12 hours, providing good postoperative pain relief. Bupivacaine is not, however, suitable for outpatient treatment, since a patient should not be sent home with a numb, paralysed arm.

Many other methods of anaesthetizing the brachial plexus are in use, but they carry greater risks of complications such as pneumothorax.

Block of the inferior alveolar nerve (dental block)

This block is suitable for certain dental procedures on the lower jaw. The inferior alveolar nerve runs inferiorly along the medial surface of the mandibular ramus and is blocked at a point just before it enters the mandibular foramen at the lingula. With the patient's mouth wide open, insert a needle just medial to the anterior border of the mandible, inside the mouth, at a point 1 cm above the occlusal (biting) surface of the lower third molar (Fig. 10.8). With the barrel of the syringe lying over the lower premolar teeth on the opposite side, slowly advance the needle, injecting a little local anaesthetic solution as you do so, keeping the syringe parallel to the floor of the mouth. After advancing approximately 2 cm, the needle will come into contact with bone. Withdraw it a fraction to prevent discomfort to the patient and slowly inject 2 ml of 2% lidocaine with epinephrine. Most oral surgeons prefer to use 12.5 μg/ml epinephrine solutions (1:80 000) if available, as 5 μg/ml solutions (1:200 000) are rather

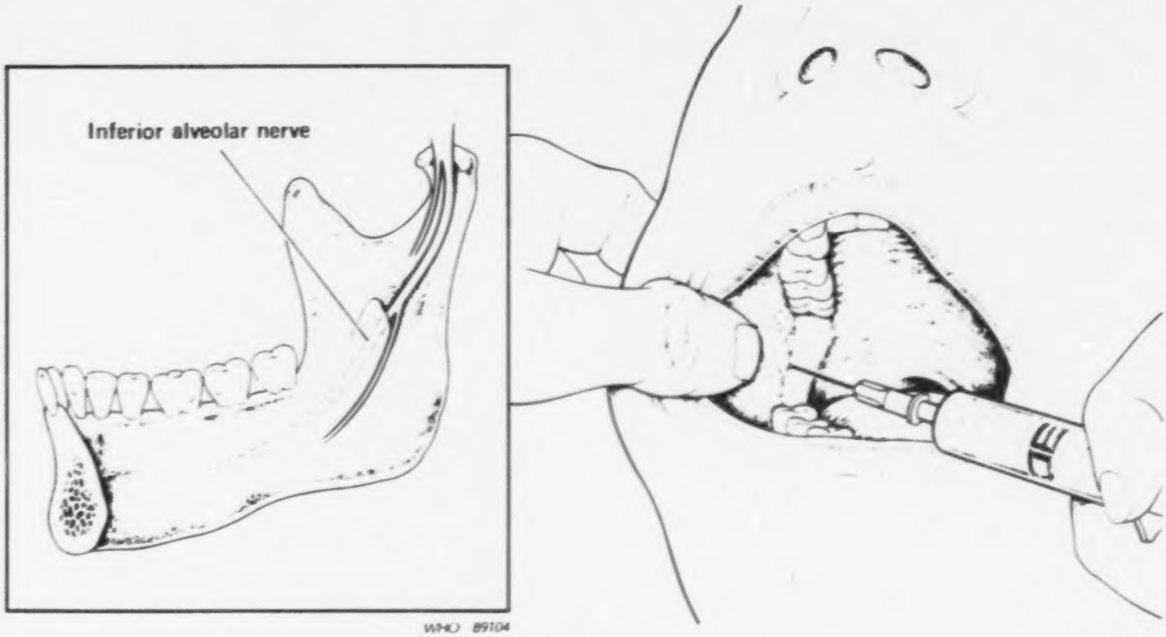

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Fig. 10.8. Block of the inferior alveolar nerve.

short-acting. If required, block of the lingual nerve may be achieved by withdrawing the needle approximately 1 cm and slowly injecting a further 1 ml of local anaesthetic solution.

Intercostal nerve block

This block can be used to provide excellent pain relief for patients with fractured ribs; it can also provide worthwhile relaxation of the anterior abdominal wall during abdominal surgery. For alleviating the pain of a fractured rib, it is obviously necessary to block the nerve of the rib concerned. For analgesia or relaxation of the abdominal wall, the intercostal nerves of the dermatomes in the region of the proposed operation need to be blocked. (The dermatome supplied by the sixth intercostal nerve is at the level of the xiphisternum, that supplied by the tenth at about the level of the umbilicus, and that supplied by the twelfth in the suprapubic region.)

For abdominal relaxation and analgesia, the nerves can conveniently be blocked in the mid-axillary line, but for fractures the block should be behind the fracture, preferably close to the angle of the rib (Fig. 10.9).

Each intercostal nerve runs parallel to the lower border of its rib in the intercostal groove, just below the intercostal artery and vein. To allow you to reach the posterior part of the rib, the patient should sit up with both arms folded over a pillow in order to move the scapula laterally and give access to the upper ribs. For the approach in the mid-axillary line, the patient can lie supine with the arm abducted. In either case, palpate the rib, and after making a small skin wheal level with the lower border of the rib, advance the needle slowly until it makes contact with bone. Inject a small amount of local anaesthetic (the periosteum is sensitive), and then "walk" the needle slowly down the rib in a caudal direction until it slips off the lower edge (Fig. 10.9). Advance the needle another 2–3 mm (but no more, as the pleura is close) and inject 2.5 ml of local anaesthetic — lidocaine 1% with epinephrine 5 μg/ml (1:200 000) or bupivacaine 0.25% with or without epinephrine. Repeat the procedure on as many ribs as necessary, but be careful not to exceed the maximum dose of anaesthetic. Pneumothorax is a potential but rare complication of this block, so watch the patient carefully afterwards.

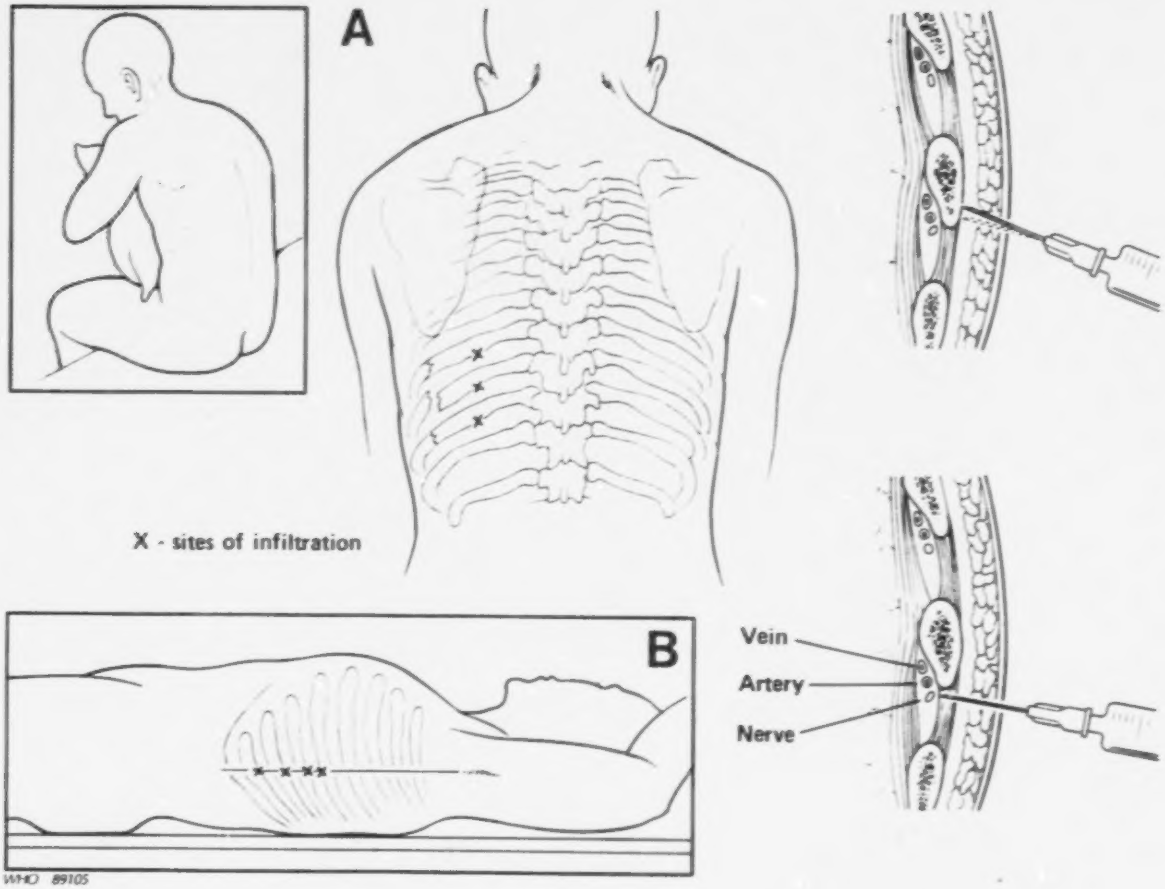

Fig. 10.9. Intercostal nerve block. (A) Suggested approach for rib fractures; (B) suggested approach for abdominal relaxation.

Femoral nerve block

This block can be used for surgery on the front of the thigh, but its main use is to provide excellent analgesia for the patient with a fractured femoral shaft. It is extremely useful when such a patient must be transported.

The femoral nerve passes under the inguinal ligament and lies lateral to the femoral artery. Block it by injecting 15 ml of 1% lidocaine into the arterial sheath (as in an axillary block) just below the inguinal ligament and lateral to the artery. Having done this, inject a further 5 ml subcutaneously, moving laterally, to block any high branches of the nerve (Fig. 10.10).

Intravenous regional anaesthesia

This technique consists of the intravenous injection of local anaesthetic drug into an arm that is isolated from the circulation by an arterial tourniquet. The technique provides good analgesia, but, because of the progressive discomfort caused by the tourniquet, its use should be limited to procedures lasting less than one hour. Sudden collapse of the patient is always a possibility and may occur if local anaesthetic drug escapes beneath the tourniquet during injection or when the tourniquet is released at the end of surgery. Full resuscitation apparatus must therefore be available.

To ensure venous access at all times, insert a cannula or needle into a vein on the side of the patient opposite the side of the proposed operation. Next, cannulate a vein in the arm to be anaesthetized and exsanguinate the arm either with an

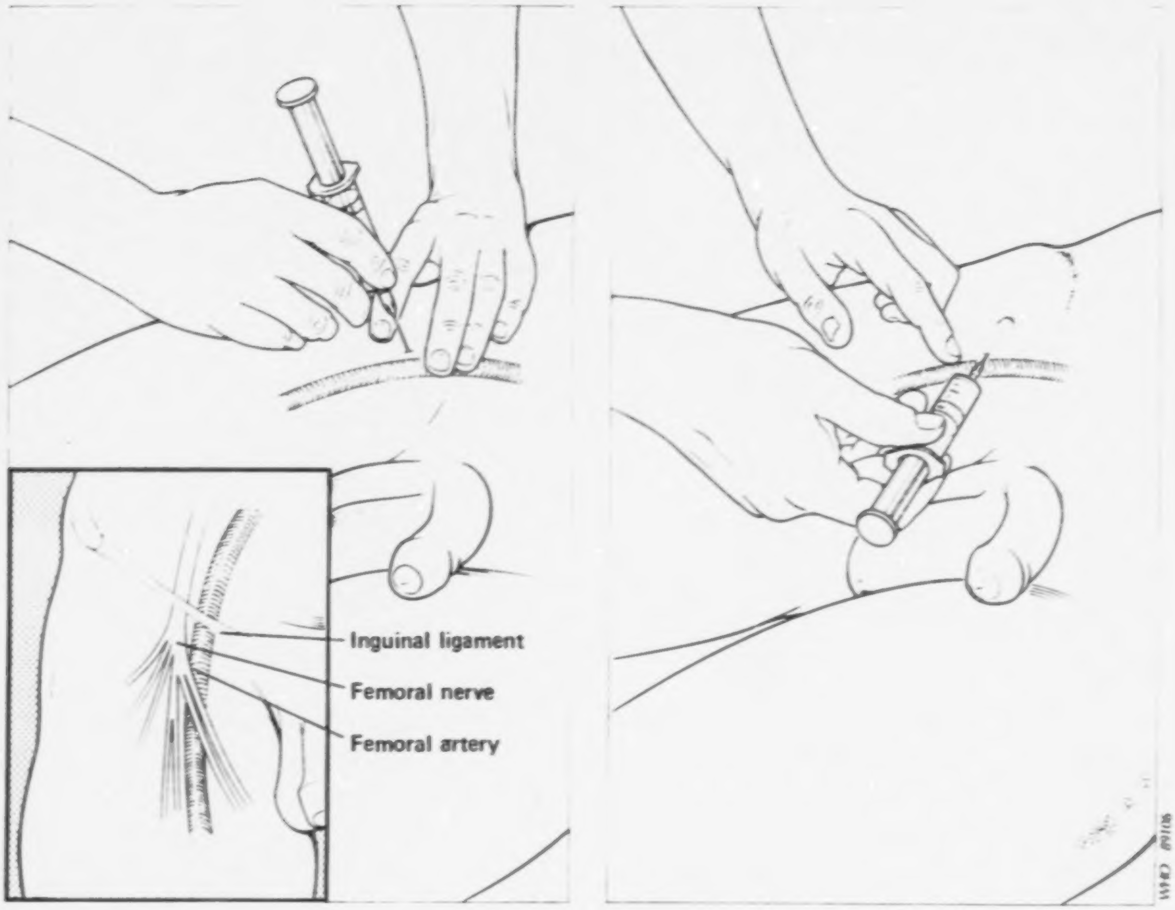

Fig. 10.10. Femoral nerve block.

Esmarch bandage or, in the case of a fracture, by simply elevating the arm for 3 min. Apply a proper arterial tourniquet (a blood pressure cuff will *not* do) and inflate it to 100 mmHg (13.3 kPa) *above* the patient's systolic blood pressure. Through the cannula in the isolated arm inject 20–40 ml of prilocaine 0.5% or lidocaine 0.5% (*without* epinephrine). Do *not* use higher concentrations or bupivacaine as these can be fatal if given intravenously. Analgesia begins in a few minutes and will last as long as the tourniquet remains inflated. However short the procedure, always leave the tourniquet inflated *for at least 20 min* to allow some of the local anaesthetic to become fixed to the tissues and to prevent systemic blood levels of the drug becoming dangerously high after release of the tourniquet.

Spinal anaesthesia

In spinal anaesthesia, a conduction block of nerve roots is achieved by injecting a small volume of concentrated local anaesthetic solution into the subarachnoid space through a lumbar puncture. Injection is made at a level below that of the first lumbar vertebra (the level at which the spinal cord terminates), frequently at the interspace between the third and fourth lumbar vertebrae. A solution denser than cerebrospinal fluid (i.e. a hyperbaric solution) is normally used, for example "heavy" lidocaine (5% lidocaine in 7.5% glucose) or "heavy" bupivacaine (0.5% bupivacaine in 7.2% glucose). These solutions allow the level of the block to be controlled by positioning the patient so that the drug flows "downhill" to the segments that need to be blocked. For example, injection with the patient in the sitting position will result in a block of the sacral nerve roots; injection with the patient in the lateral position, if the position is maintained, will produce unilateral anaesthesia on the lower side.

Successful spinal anaesthesia always produces a considerable block of the sympathetic nerves, resulting in widespread vasodilatation and a fall in blood pressure, which may be dangerous. The best way to prevent such a fall is to infuse intravenously 0.5–1 litre of saline or Hartmann's solution (for an adult) before the spinal injection. The management of the patient whose blood pressure has fallen unacceptably, in spite of these precautions, is detailed on p. 101.

Indications for spinal anaesthesia

Spinal anaesthesia can be used for almost any operation in the lower abdomen (including caesarean section), perineum, or leg. It gives very good relaxation, but the duration of anaesthesia with lidocaine is limited to about 90 min. If other drugs such as bupivacaine, cinchocaine, or tetracaine are available, the duration of anaesthesia can be extended to 2–3 hours.

Contraindications to spinal anaesthesia

- Spinal anaesthesia is contraindicated in a patient with uncorrected or undercorrected hypovolaemia. Before anaesthesia, the hypovolaemic patient may be able to sustain a relatively normal blood pressure by extensive vasoconstriction, but the sympathetic blockade that accompanies spinal anaesthesia and overrides this reflex will produce severe cardiovascular collapse. In an emergency, general anaesthesia is usually safer.
- A patient with severe uncorrected anaemia or heart disease should also not be given spinal anaesthesia, since if hypotension occurs the patient's condition could be worsened.
- Never use spinal anaesthesia on a patient who may have raised intracranial pressure — for example a patient with a brain tumour or recent head injury.
- As for other local anaesthetic techniques, local sepsis and anticoagulant therapy are contraindications.

Specimen technique

As with all other conduction blocks, full resuscitation equipment and the necessary drugs must be available and checked before starting. Set up an intravenous infusion and "preload" the patient with 500 ml of physiological saline. (The blood pressure falls fairly rapidly after spinal anaesthesia at all but the lowest levels of the spine, so it is better to be slightly ahead with fluid therapy.) Position the patient carefully in the sitting or lateral position, with the lumbar spine well flexed. It is easier to do this if you ask the patient to flex his or her head on to the chest in addition to flexing the spine and hips. Your assistant will need to support and hold the patient in position. With a marker or ball-point pen, draw the outlines of the lumbar spinous processes on the skin to help you to visualize the spinal anatomy. Mark your proposed site of injection and scrub your hands more thoroughly than the surgeon. (The surgeon has only to avoid causing a wound infection; you have to avoid causing meningitis!) Put on sterile gloves and thoroughly prepare the skin over a wide area of the back; place sterile towels around the proposed site of injection in such a way that they will not fall down and obscure your view. Choose a fine-gauge needle with a stylet; fine needles produce a lower incidence of postspinal headache. (The lowest incidence of headache is with a pencil-point type of needle.) Do not touch the shaft of the spinal needle, which should either be a sterile disposable one or have been autoclaved — boiling is inadequate.

Choose whichever interspace below the second lumbar vertebra feels easiest to penetrate; a line joining the iliac crests usually passes through the level of the fourth lumbar vertebra or the interspace between the third and fourth lumbar vertebrae (Fig. 10.11). Raise a skin wheal with local anaesthetic over the chosen space in the midline and insert the spinal needle through the skin, supraspinous

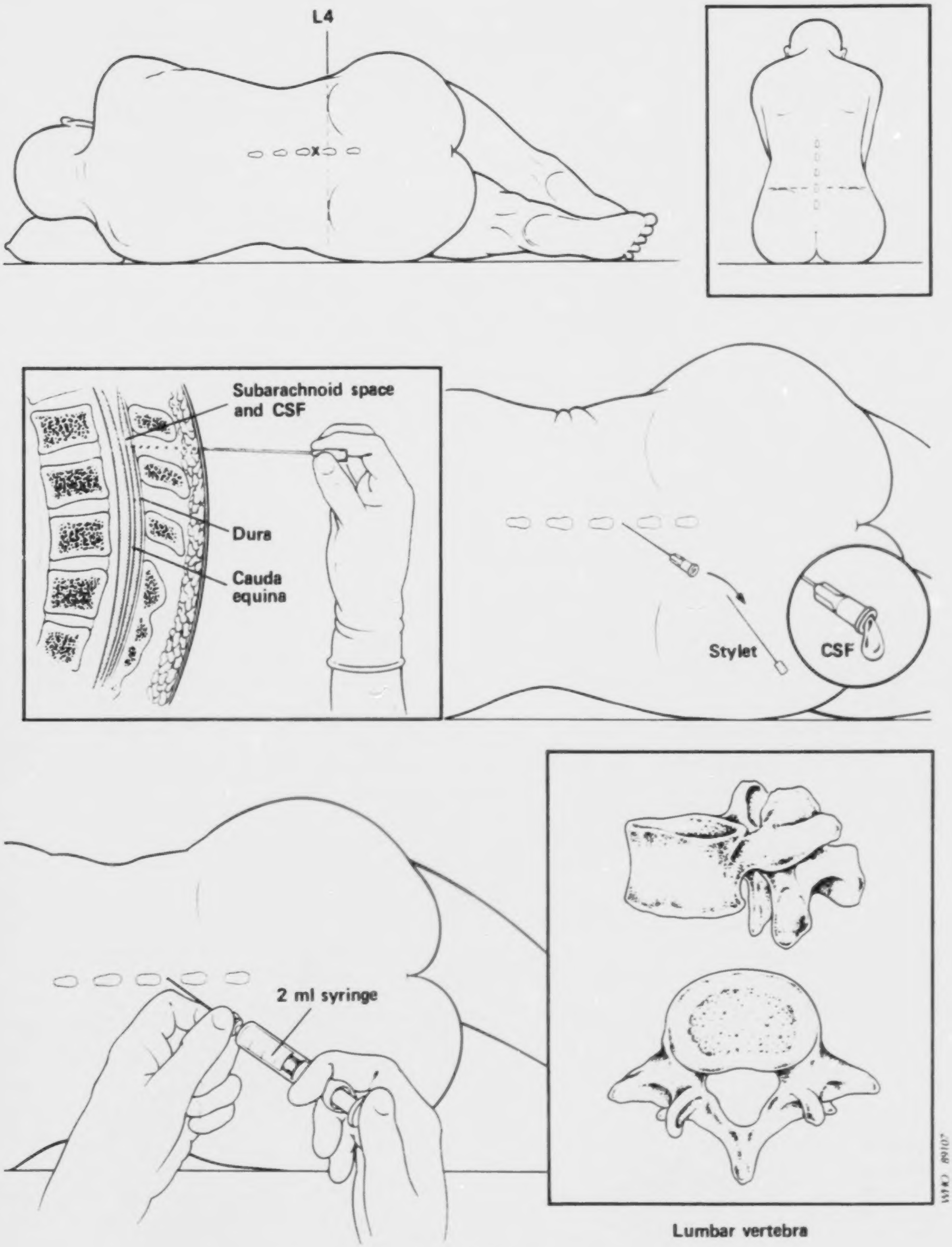
L4
Subarachnoid space and CSF
Dura
Cauda equina
Stylet
CSF
2 ml syringe
Lumbar vertebra
WHO 89107

Fig. 10.11. Technique of spinal anaesthesia.

ligament, interspinous ligament, and ligamentum flavum. The needle should stay in the midline, but will need to be directed slightly towards the head to pass through the interspace. If you strike bone superficially, it is probably the spine of the vertebra above, so make a new start 1 cm further down. If you strike bone deep, it is the vertebra below, and you will need to angle the needle more towards the head. If the ligaments are calcified, move 1 cm laterally from the midline and try again, aiming for the midline as you advance the needle gradually. Once the needle has passed through the ligamentum flavum, remove the stylet and advance slowly. You may feel the needle enter the dura, and cerebrospinal fluid will start to flow out of the needle (see Fig. 10.11). If it does not, try rotating the needle through 90 degrees, as a nerve root may be lying across the bevel. Once cerebrospinal fluid flows, connect the syringe and inject your drug, ensuring that the needle does not move. A small aspiration of 0.1 ml of liquid at the end of injection confirms that the needle has remained in the cerebrospinal fluid.

To block the sacral roots only, for example for surgery of the perineum, inject 1 ml of "heavy" lidocaine (5% lidocaine in 7.5% glucose) with the patient in the sitting position; the patient should then remain sitting for 3 min.

For a higher block, for example for surgery of the legs and abdomen below the umbilicus, inject 1.5 ml with the patient in the lateral position and lie him or her supine with a 5-degree head-down tilt and one pillow under the head.

Complications of spinal anaesthesia

Failed spinal anaesthesia

Even experienced experts occasionally find that they are unable to perform a successful spinal injection. If you do not succeed in entering the dural sac (as demonstrated by cerebrospinal fluid dripping from the needle or being aspirated) it is not worth injecting local anaesthetic in the hope that it may work. Remember that a nerve root can block the needle tip, and it is worth rotating the needle through 90 degrees, as this may allow CSF to flow. If you cannot produce CSF, try again, moving up or down one inter-space. If the patient is not distressed a maximum of 3 attempts may be permissible, after which you should consider alternative means of anaesthesia. If you do succeed in producing CSF flow, make sure that the spinal needle does not move during injection. A "successful" injection may produce an inadequate block if you use the wrong volume of drug, or fail to position the patient correctly. Always check the level of your block before allowing surgery to begin.

Hypotension

A fall in blood pressure is common after spinal anaesthesia. It usually occurs in the first 10 min after injection, so measure the blood pressure every 2 min during this period. If systolic blood pressure falls below 75 mmHg (10 kPa), or if the patient has symptoms (such as confusion, faintness, or nausea) from any fall in blood pressure, you must act quickly to avoid renal, cardiac, or cerebral damage. Give the patient oxygen and increase the drip rate; you may need to give a litre of fluid to restore the blood pressure. If the heart rate is below 65 beats per minute, give atropine 0.5 mg intravenously. Also consider the use of a vasopressor drug such as ephedrine, 5–25 mg given intravenously. Very rarely, a "total spinal" block develops, with anaesthesia and paralysis of the whole body, in which case you will have to intubate the patient and ventilate the lungs, as well as treat the severe hypotension. With this management, the patient should come to no harm, and the total spinal block will wear off in a couple of hours.

Spinal headache

Headache in the postoperative period is a recognized complication of spinal anaesthesia. Spinal headache is typically worse on sitting or standing and disappears on lying down. It is frontal or occipital and is not associated with neck rigidity. It is caused by loss of cerebrospinal fluid from the brain through the dural puncture — the larger the hole, the greater the chance of headache. It can be prevented by keeping the patient flat (allow one pillow) for 24 hours. If the headache still appears when the patient gets up, keep the patient flat and give plenty of fluids orally (or intravenously if necessary) and simple analgesics. Continue this treatment for 24 hours after the headache disappears, at which time the patient can be mobilized.

112

11

Choosing and planning your anaesthetic technique

In anaesthesia, as in most areas of medicine and surgery, you will need at least as much knowledge and skill to make the right choice of technique as you will to implement it. This book cannot tell you which anaesthetic to choose. The best anaesthetic in any given situation depends on your training and experience, the range of equipment and drugs available, and the clinical situation.

One "golden rule" is worth remembering: *however strong the indications may seem for using a particular technique, the best anaesthetic technique, especially in an emergency, will be one with which you are most experienced and confident.*

Some of the factors to bear in mind when choosing your anaesthetic technique are:

- training and experience of the anaesthetist and surgeon
- availability of drugs and equipment
- medical condition of the patient
- time available
- emergency or elective procedure
- presence of a full stomach
- patient's preference.

Not all these factors are of equal importance, but all should be considered, especially when the choice of technique is not obvious.

Choice of anaesthetic technique for a particular operation

Table 6 is intended to help you decide what type of anaesthetic might be most suitable for a given surgical procedure. For minor emergency operations (for example the suture of a wound or manipulation of an arm fracture), when the patient probably has a full stomach, conduction (regional) anaesthesia is probably the wisest choice. For major emergency operations, there is often little difference in safety between conduction and general anaesthesia. It is a dangerous mistake to think that conduction anaesthesia is always safe!

When you have come to a decision, discuss it with the surgeon and theatre team, who may give you further relevant information. For example, the proposed operation may need more time than can be provided by the technique you have suggested, or the patient may need to be placed in an abnormal position. Also check that you have all the drugs and equipment you may need.

Table 6. Suitable anaesthetic techniques for different types of surgery

Type of surgery	Suitable anaesthetic technique
Major head and neck Upper abdominal Intrathoracic ENT Endoscopic	General tracheal
Lower abdominal Groin, perineum Lower limbs	General tracheal *or* Spinal *or* Nerve or field block *or* Combined general and conduction
Upper limbs	General tracheal *or* Nerve block *or* Intravenous regional

By now you will probably have decided, in principle, on one of the following techniques:

- general anaesthesia with drugs given intravenously or by inhalation
- general anaesthesia with intramuscular ketamine
- spinal anaesthesia
- nerve block
- infiltration anaesthesia.

There can be advantages in combining light general anaesthesia with a conduction block because such a technique reduces the amount of general anaesthetic that the patient requires and allows a rapid recovery, with postoperative analgesia provided by the remaining conduction block.

Planning general anaesthesia

Figure 11.1 shows the possibilities you should consider when planning general anaesthesia. The right-hand side of the diagram shows what is effectively a universal anaesthetic technique, which can be used for almost any operation and which you should master and practise regularly.

For general anaesthesia, tracheal intubation should be routine, unless there is a specific reason to avoid it. Tracheal intubation is the most basic of anaesthetic skills, and you should be able to do it confidently whenever necessary. In smaller hospitals, most of the operations are emergencies, and the lungs and lives of the patients are in danger if you do not protect them by this manoeuvre.

Remember that all relaxants are contraindicated prior to tracheal intubation if the patient has an abnormality of the jaw or neck or if there is any other reason to think that laryngoscopy and intubation might be difficult.

If you find intubation unexpectedly difficult after giving the patient suxamethonium and you do not succeed in intubating within 30 s of starting laryngoscopy, you must restore oxygenation by ventilating the patient with a face mask for 10 good breaths. Make one more attempt, and if you are still unsuccessful after another 30 s, adopt the "Failed intubation drill" (see p. 14).

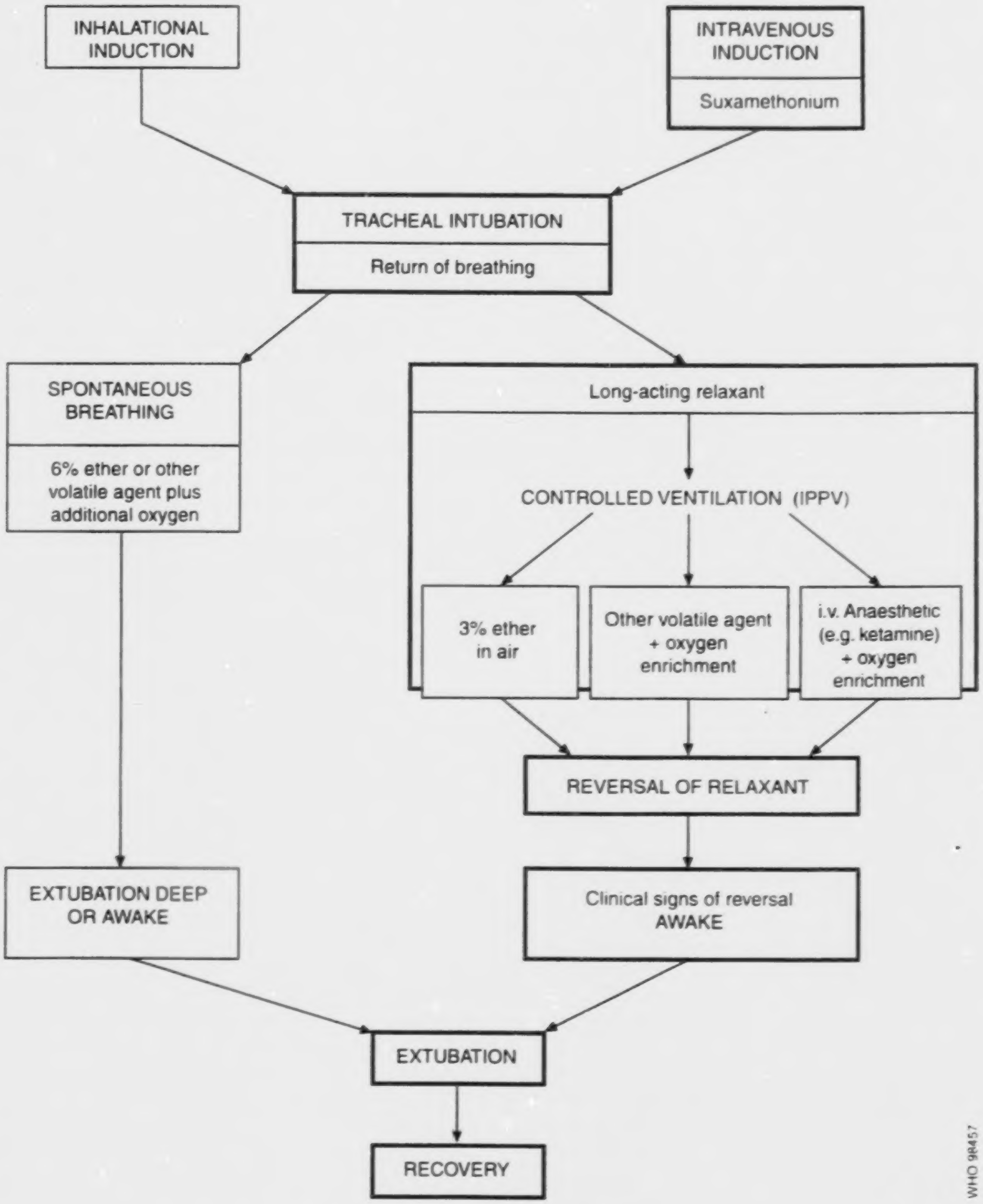
INHALATIONAL INDUCTION
INTRAVENOUS INDUCTION
Suxamethonium
TRACHEAL INTUBATION
Return of breathing
SPONTANEOUS BREATHING
6% ether or other volatile agent plus additional oxygen
Long-acting relaxant
CONTROLLED VENTILATION (IPPV)
3% ether in air
Other volatile agent + oxygen enrichment
i.v. Anaesthetic (e.g. ketamine) + oxygen enrichment
REVERSAL OF RELAXANT
Clinical signs of reversal AWAKE
EXTUBATION DEEP OR AWAKE
EXTUBATION
RECOVERY
WHO 98457

Fig. 11.1. Planning a general anaesthetic technique.

Safety of general and conduction techniques

In general, there are potential risks with all types of anaesthetic. These can be minimized by careful assessment of the patient, thoughtful planning of the anaesthetic technique, and skilful performance by the anaesthetist. You should keep records of all the anaesthetics that you give (see Annex 3 for specimen chart) and regularly review complications and morbidity. Some of the possible complications to look for are listed in Table 7.

Table 7. Some complications of general and conduction anaesthesia

General anaesthesia	Conduction anaesthesia
Airway obstruction	Toxicity of drug
Aspiration of gastric contents into the lungs	Accidental intravascular injection
Allergy or hypersensitivity	Allergic reactions
Hypotension (including supine hypotension in pregnancy)	Massive spread of spinal anaesthetic
Cardiac dysrhythmias	Cardiac depression by local anaesthetic drug
Trauma to mouth, pharynx, larynx, and teeth	Spread of sepsis
Respiratory depression	Depression of the central nervous system and convulsions
Increased intracranial pressure	
Postoperative hypoxia	
Toxic damage to liver or kidneys	

12
Postoperative care of the patient

As an anaesthetist, your responsibility includes the care of your patient while he or she is recovering from the effects of anaesthesia. Ensure that a trained nurse or assistant is available to observe the patient closely and make regular measurements and recordings of pulse rate, blood pressure, and respiratory rate, as well as to watch for and report any abnormal and continuing blood loss.

The first hour after anaesthesia is a potentially dangerous time for the patient. Protective airway reflexes are still depressed to some extent, even if the patient appears to be awake, and the residual effects of the drugs that you have given may lead to respiratory depression. Pain from the patient's wound, especially if it is in the upper abdomen or thorax, will prevent him or her from taking deep breaths or coughing effectively. This may lead to the development of a chest infection or collapse of the lung bases with further hypoxia. Patients who have not fully recovered consciousness should be nursed in the semiprone position, but patients with abdominal incisions, once fully awake, will usually find breathing easier in the reclining or sitting position. Oxygen may be given and should be routine for sick patients and for those who have had prolonged operations. The most economical way to give oxygen during recovery is with a soft nasopharyngeal catheter and a flow of 0.5–1.0 litres/min, which will usually produce a concentration of 30–40% oxygen in the inspired air. If the patient has pain, it should be controlled. If a strong, i.e. opiate, analgesic is needed, give the first dose intravenously, so that you can titrate the dose against the patient's pain and also observe any untoward respiratory depression. You can then prescribe the dose given intravenously for regular intramuscular use if required, with some confidence that analgesia will be adequate and the dosage safe.

Where should the patient recover?

Probably the safest place for the patient to recover is the operating theatre itself, since all necessary equipment and drugs are close by for access in the event of any mishap. It is often more convenient to move the patient out to a recovery area, so that the theatre can be cleaned and prepared for the next operation.

Any recovery area must:

- be clean and well lit;
- be near to the operating theatre so that you can visit the patient easily and quickly whenever needed;
- be properly equipped with facilities for:
  - — oxygen therapy;
  - — suction;
  - — resuscitation.

Control of postoperative pain

Many patients suffer severe pain after operations. It is made worse if patients are frightened or do not understand what to expect after their operation. Explain

117

during the preoperative visit that pain-killing drugs are available and will be used as much as necessary.

The best time to start effective pain treatment is when patients are under close observation in the recovery area. Many patients are afraid to complain about pain and need to be specifically asked about it. It is important where possible to prevent postoperative pain by choosing the right anaesthetic technique. Pain can often be prevented by administering analgesic drugs before the patient wakes up, or by combining light general anaesthesia with conduction anaesthesia.

If the patient wakes up with severe pain, opiate analgesics given intravenously in small, regular doses (up to 1 mg of morphine or 10 mg of pethidine every 5 min until pain is relieved) are both effective and safe. Giving frequent small doses also allows you to observe the drug's effect, and to make an estimate of the dose that can later be safely given on the ward. As needs and sensitivities vary, adjust the dosage to each individual patient, and do not try to use the same dosage for all. Do not use diazepam to quieten a patient in pain — it is not an analgesic, and you would in effect be re-inducing anaesthesia which is unsafe.

Make sure that nurses on the ward ask regularly whether more pain relief is needed. Morphine and pethidine can safely be given every 3 hours if required. Later on, patients who no longer require opiates can be given oral analgesics such as codeine, non-steroidal anti-inflammatory drugs, aspirin, or paracetamol. Make sure that analgesic drugs are given by an appropriate route — it is useless to give oral drugs to a patient who is vomiting, or intramuscular drugs to a patient who is severely vasoconstricted because of hypovolaemia or hypothermia. Special care is needed to make sure that children's needs are met.

You must see each patient before he or she leaves the recovery area and make a quick assessment by asking yourself the following questions:

- Does the patient have a good colour (mucous membranes, skin, etc.) when breathing air?
- Is the patient able to cough and maintain a clear airway?
- Is there any evidence of obstruction or laryngeal spasm?
- Can the patient lift his or her head from the bed for at least 3 s?
- Are the patient's pulse rate and blood pressure stable?
- Are the hands and feet warm and well perfused?
- Is there a good urinary output?
- Is the patient's pain controlled, and have necessary analgesics and fluids been prescribed?

Postoperative visiting and record-keeping

You should always visit your patients postoperatively on the ward to see whether any further treatment is necessary during recovery from the effects of anaesthesia. Keep a **record** (separate from the case notes) of the anaesthetic technique you used and of any complications. This will not only be of great interest to you in future, but will also help the next time you have a similar patient to anaesthetize. A good anaesthetist, however experienced, learns something from each case.

It is also important to have a system to record what happens when things go wrong. This will allow you to identify any risk factors and to avoid them, as well as to warn your colleagues about them.

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13

Paediatric and obstetric anaesthesia

Although the general principles of anaesthesia for adults outlined in this book are widely applicable, physiological differences in pregnant women and in children often make it necessary to use slightly different anaesthetic techniques for such patients and to take special care of them.

Anaesthesia for children

Most of the general principles of anaesthesia can be applied to children, but there are some significant anatomical and physiological differences between children and adults that can cause problems, especially in neonates and children weighing less than about 15 kg.

Anatomical differences and problems

The airway

A child has a large head in relation to body size and you must therefore position a child differently from an adult, sometimes with a pillow under the shoulders rather than the head, to clear the airway or to perform laryngoscopy (see Fig. 2.6, p. 9). The larynx of a child also differs from that of an adult. In the adult the narrowest part of the air passage is at the level of the vocal cords; in the child the narrowest part is below this, at the level of the cricoid cartilage. The airway here is circular in cross-section, so a correct fit can usually be obtained with a plain (not cuffed) tracheal tube. A small air leak should usually be present around the tube, but if a completely airtight fit is required, pack the pharynx with gauze moistened with water or saline; never use liquid paraffin (mineral oil), as this causes lung damage. Do not use a cuffed tube with an internal diameter less than 6.0 mm.

Because the airway of a child is narrow, a small amount of oedema can produce severe obstruction (Figure 13.1). Oedema can easily be caused by forcing in a tracheal tube that is too tight, so if you suspect that your tube is too large change it immediately. Damage is most likely from a tube that is both too large and left in the trachea too long. As a rough guide for normally nourished children more than about 2 years old, the internal diameter of the tube likely to be of the correct size can be calculated from the following formula, but you should always have one size larger and one smaller ready in case you need to change.

$$\text{Internal diameter (in mm)} = \frac{\text{Age (in years)}}{4} + 4.5$$

Another rough indicator of the correct size of tube is the diameter of the child's little finger. To estimate the length of tube needed, double the distance from the corner of the child's mouth to the ear canal; to check, look at the child's head

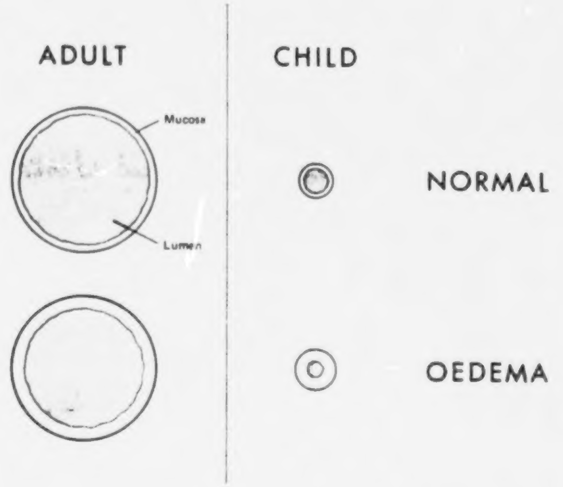

Fig. 13.1. The effects of mucosal oedema in the airway (shown in cross-section).

from the side while holding the upper end of the tube level with the mouth to give you an idea of how far into the chest the tube will go. After intubation, always listen over both lungs to make sure that the tube has not entered a bronchus. Most neonates will need a tube of 3 mm internal diameter, though for premature infants a 2.5 mm tube may be necessary.

For intubating infants, many anaesthetists prefer to use a small straight laryngoscope blade (see Fig. 13.4, p. 116). If one is not available, the tip of a Macintosh blade designed for adults can be used, as it is only slightly curved.

The abdomen

A child's abdomen is more protuberant than an adult's and contains the greater part of the viscera (many of the viscera of an adult are situated in the relatively larger pelvic cavity). The diaphragm is therefore less efficient in a child. The rib cage is also less rigid than an adult's. These factors mean that abdominal distension can very easily give rise to respiratory difficulty.

Physiological differences and problems

Metabolism and heart rate

The metabolic rate is higher in children than in adults, while the lungs are less efficient and smaller in relation to oxygen requirements. For this reason, children have higher respiratory rates than adults and their lungs must be ventilated more rapidly. Obstruction or apnoea leads to a very rapid onset of cyanosis. The heart rate is also higher than that of an adult, but the resting sympathetic tone is low, so reflex vagal stimulation can lead to severe bradycardia, for example during laryngoscopy or surgery. For this reason, atropine (0.015 mg/kg of body weight) is almost always included in premedication for infants.

Hypothermia

Hypothermia can occur very rapidly in an infant because of the high surface-to-volume ratio of the body; it may result in a severe metabolic disturbance. Take active steps to prevent hypothermia in any operating theatre with an ambient temperature below 26°C. Carefully wrap the infant, including the head, which is a major source of heat loss; warm up antiseptic solutions before use on the skin; and protect the infant from draughts.

Hypoglycaemia

Hypoglycaemia may be a problem in babies. They do not need to be starved for more than 3 hours preoperatively and should be fed as soon as possible after the operation. Glucose infusions should be used during anaesthesia to help to maintain the blood sugar level. Infusing glucose instead of physiological saline also avoids a sodium load that the baby's kidneys are unable to excrete.

Circulation

The normal heart rate at birth is about 140 per minute, but it may swing widely in response to stress. The neonate has a proportionately higher blood volume (90 ml/kg of body weight) than the adult (70 ml/kg), but even so, what appears to be a small blood loss may have serious effects. Blood losses during the operation must be measured as accurately as possible. If suction apparatus is in use, a simple method is to use a measuring cylinder in the suction line rather than the usual large container. If blood loss amounts to more than 5% of blood volume, an intravenous infusion is necessary; if losses exceed 10% of blood volume, blood transfusion is indicated. For most paediatric operations, other than minor ones, it is routine to give glucose 5% (or glucose 4% with saline 0.18%) at a rate of 5 ml/kg of body weight per hour in addition to replacing the measured fluid losses.

Technical problems

Most children weighing more than 15 kg can be anaesthetized by using the techniques described in this book for adult patients, but with the dosage reduced in relation to weight. In children below 15 kg, the anatomical and physiological differences described above become more important and inhalational apparatus must be adapted, although ketamine can be used without any modifications in technique.

Draw-over anaesthesia for infants

"Adult" breathing systems give rise to problems in small children because the valves have too large a dead space. In addition, vaporizers of the draw-over type do not work effectively at the low minute-volumes and flows generated by an infant's lungs. These problems can be overcome in a number of ways.

- Replace the adult-size breathing valve with an infant-size valve that has a smaller internal volume and dead space. If possible, replace the adult-size SIB with a small bellows or infant resuscitator bag. You must use intubation and controlled ventilation for infants under 10 kg; the flow you generate into the bellows during IPPV will be enough to allow the vaporizer to work reasonably accurately.
- If oxygen is available, you can convert your draw-over system to a continuous-flow mode by connecting a flow of oxygen from a cylinder or concentrator (or oxygen plus nitrous oxide) to the side-arm of your oxygen-enrichment T-piece and closing off the open end with a bung (Figure 13.2). You should set the fresh gas flow to 300 ml/kg of body weight per minute with a minimum of 3 litres/min. Intubate and ventilate the patient or allow spontaneous breathing using an Ayre's T-piece system, as described below.

Continuous-flow anaesthesia for infants

Use a T-piece system (Ayre's T-piece) instead of the Magill breathing system usually used for adults. The valveless T-piece system requires a relatively high gas flow, but is suitable for both spontaneous and controlled ventilation. Spontaneous breathing can be monitored by watching the slight movement of the open-ended reservoir bag. To change to controlled ventilation, hold the bag in your hand with your thumb towards the patient, partly occlude the outlet by curling your little finger round it (this needs practice), and squeeze the bag in the palm of your hand to inflate the lungs (Figure 13.3). Then release the bag to allow the expired gas to escape.

Monitoring paediatric patients

Continuous monitoring of heart rate and respiration is essential in small children, and a precordial or oesophageal stethoscope is invaluable for this. Use an infant-sized cuff to measure the blood pressure. Palpate the arterial pulses and

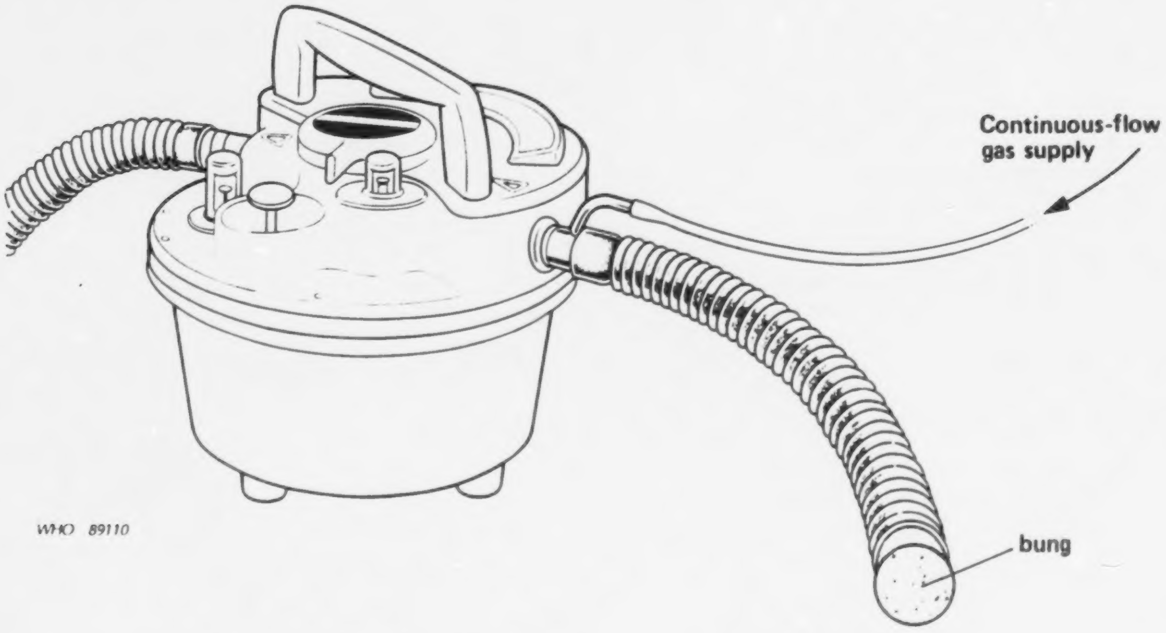
Continuous-flow gas supply
bung
WHO 89110

Fig. 13.2. Conversion of draw-over to continuous-flow apparatus.

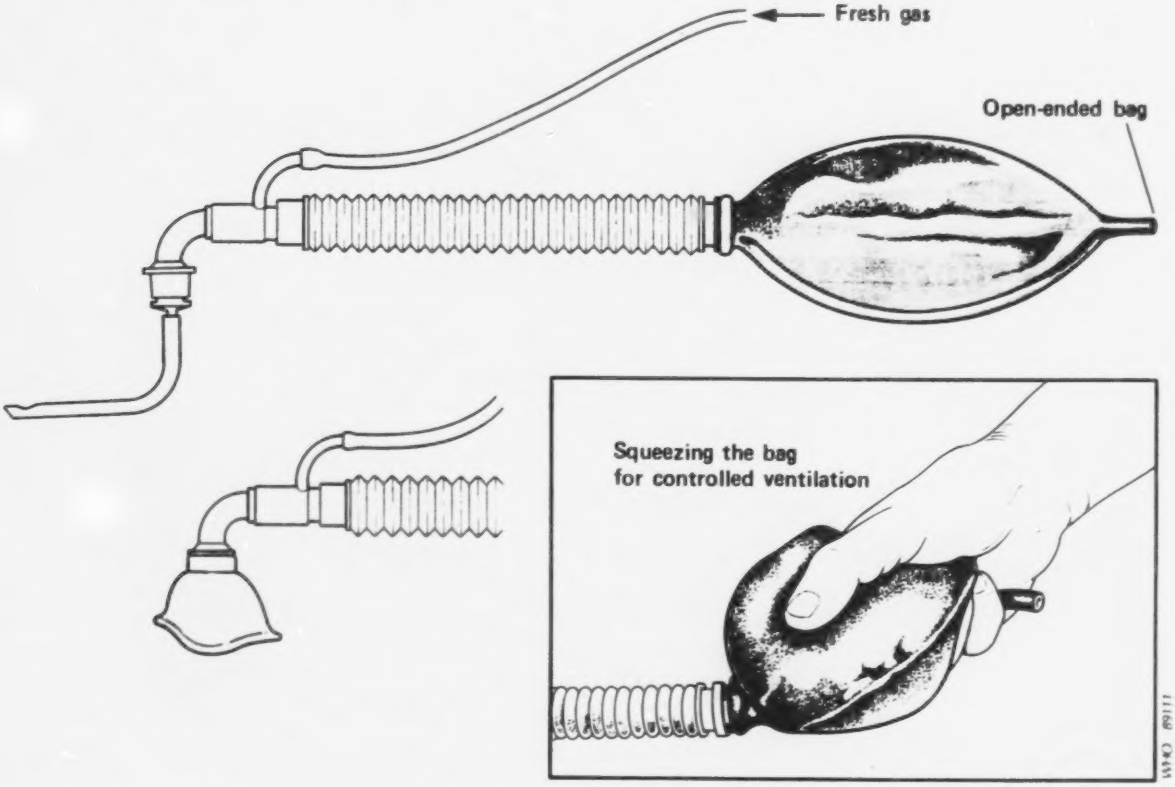
Fresh gas
Open-ended bag
Squeezing the bag for controlled ventilation
WHO 89111

Fig. 13.3. The T-piece breathing system for infants.

check the colour and perfusion of the extremities. Monitor the urine flow if a urinary catheter is in place; a good urine output (0.5 ml/hour per kg of body weight) is reassuring. At the end of the operation, check the rectal temperature to ensure that the patient has not become hypothermic.

Anaesthesia during pregnancy and for operative delivery

Physiological changes of pregnancy

Several changes occurring in pregnancy are relevant to anaesthesia. Fairly early in pregnancy the blood volume begins to rise, as does the cardiac output. The increase in plasma volume is not matched by an equivalent increase in the number of red cells, so the haemoglobin concentration falls. As the uterus enlarges, respiration comes to depend more on thoracic than diaphragmatic movement. Gastric emptying becomes less efficient, and a woman who needs anaesthesia in the later stages of pregnancy must therefore always be regarded as having a full stomach.

Supine hypotensive syndrome

In late pregnancy, the uterus presses back on the inferior vena cava when the patient lies on her back and this causes a fall in cardiac output. There may also be a severe fall in blood pressure — the "supine hypotensive syndrome" — but most non-anaesthetized patients are able to maintain their blood pressure by widespread vasoconstriction.

During general or spinal anaesthesia, the capacity for vasoconstriction is lost; this is likely to result in a severe fall in blood pressure to levels dangerous for both mother and baby. *The condition of supine hypotension can be prevented merely by ensuring that the mother is never fully supine. A pillow or sandbag must always be placed under one hip to tilt the uterus slightly to one side; this is perfectly simple to do even with the patient in the lithotomy position.* This simple precaution must always be carried out in obstetric patients receiving either general or spinal/epidural anaesthesia.

Anaesthesia for operative delivery at term

When you anaesthetize a pregnant woman for delivery, remember that you have two patients to deal with: mother and child. Most drugs cross the placenta quickly. This is a problem, since the aim is to anaesthetize the mother, but to allow the baby to be born without any drug-induced depression of body functions, especially of respiration. For this reason, drugs that can cause depression of the fetus, such as sedative premedication, should not be given. Gallamine also crosses the placenta, and its use should be avoided before the umbilical cord is clamped. If a muscle relaxant is necessary, either use another non-depolarizing relaxant drug if available or give increments of suxamethonium until the cord is clamped.

General anaesthesia for operative delivery

A suitable general anaesthetic technique (for caesarean or forceps-assisted delivery or for vacuum extraction) is outlined below.

1. Before inducing anaesthesia give a 30-ml dose of a liquid antacid, such as sodium citrate 0.3 mol/litre (77.4 g/litre), to neutralize excess gastric acid. Insert a wedge or cushion under one hip to tilt the uterus off the inferior vena cava. *Never induce anaesthesia with the patient in the lithotomy position. If she is already in that position, her legs must be lowered for induction to avoid regurgitation of gastric contents.*

2. Set up a fast-flowing infusion of an appropriate fluid into a large vein and pre-oxygenate the patient.
3. Induce anaesthesia as for an emergency (see p. 76): after pre-oxygenation apply cricoid pressure, administer a previously calculated dose of thiopental or ketamine, intubate the patient after giving suxamethonium, and give IPPV with a muscle relaxant. In a pregnant woman at term, intubation is sometimes more difficult than usual. Always prepare a spare tube of a small size (5–6 mm) in case the patient has laryngeal oedema secondary to pre-eclampsia.
4. Do not use high concentrations of ether or halothane, as these will reduce the uterine tone and increase bleeding. Ether 5% is safe and will provide sufficient anaesthesia, even in a patient who has received no premedication. You may give opiates intravenously if necessary once the umbilical cord is clamped.
5. Be prepared to give an oxytocic drug (ergometrine or oxytocin) intravenously when requested by the surgeon, but never give ergometrine to a woman with pre-eclampsia as it may cause a hypertensive crisis.
6. The average blood loss from caesarean section is 600–700 ml, so make sure that you give enough fluid replacement. You may well need to transfuse blood.
7. In addition to looking after the mother, you may have to resuscitate the baby, so be prepared with infant resuscitation equipment and a separate oxygen supply (for more details, see p. 115). If mother and child are both critically ill, it is your clear duty to attend to the mother first. *Always* try to have a trained assistant with you for these cases.
8. At the end of anaesthesia, remember that the mother still has a full stomach: remove the tracheal tube with her in the lateral position.

Spinal anaesthesia for operative delivery

Low forceps delivery

A low spinal anaesthetic or "saddle block" is ideal for this. Set up an intravenous infusion of an appropriate fluid and inject 1 ml of "heavy" lidocaine (5% lidocaine in 7.5% glucose) with the patient supported in the sitting position. There is then little risk of hypotension, but a wedge should still be used to keep the patient's pelvis tilted when she is put into the lithotomy position, and her blood pressure should be checked every 2 min for at least 10 min.

Caesarean section

Spinal anaesthesia is a technique commonly used for caesarean section. When given by an experienced anaesthetist for an elective caesarean section it can be safe and very effective. *Nevertheless, it represents a major physiological disturbance and may be dangerous or even fatal in emergencies, when the patient may be dehydrated, hypovolaemic, or in shock.* For patients undergoing emergency caesarean section, the recommended techniques are general anaesthesia with ketamine, general inhalational anaesthesia, or local infiltration techniques.

Caesarean section requires a high-level block, at about the sixth thoracic vertebra. Preload the patient with 500–1000 ml of physiological saline, Hartmann's solution, or plasma expander before your lumbar puncture. Inject about 2–2.5 ml of 5% "heavy" lidocaine with the patient in the lateral position, and turn her into the horizontal position immediately after injection, but with the pelvis wedged as described above. Be extra vigilant, and actively treat any fall in systolic blood pressure to below 90 mmHg (12.0 kPa), as hypotension can harm both fetus and mother. The initial treatment of hypotension is to give up to 100 ml of colloid or crystalloid solution rapidly (within 5 min or less). If the pressure remains low, give a vasoconstrictor (e.g. ephedrine) in 5–10 mg increments and consider using a continuous ephedrine infusion (30 mg in 500 ml).

Always give oxygen to the mother during the operation.

Postspinal headache can be a problem, as the mother will need to sit up to nurse the baby, so ensure continuing good hydration for the mother postoperatively.

Anaesthesia for ruptured ectopic pregnancy

The patient will often be a young woman who may be desperately ill with unrecordable blood pressure. Speed is vital. Set up an intravenous infusion of an appropriate fluid using any available large vein — even the femoral vein if necessary. After pre-oxygenation, a rapid induction of anaesthesia with ketamine and suxamethonium is recommended, proceeding to intubation and controlled ventilation with 3% ether in oxygen. Put in several more intravenous lines as soon as you can; the surgeon may be able to put a catheter temporarily into a pelvic vein for rapid transfusion. In suitable cases, the blood from the abdomen can be filtered and reinfused into the patient (autologous transfusion — see p. 41).

Resuscitation of the newborn infant

In a small hospital, you as the anaesthetist may have the added responsibility of immediate care of the newborn baby, especially after an operative delivery. In these circumstances, you must check before anaesthetizing the mother that the necessary neonatal resuscitation equipment is available (Table 8 & Figure 13.4).

Initial assessment

Many babies require a short period of resuscitation after a difficult birth. Keep the baby warm and gently suck out secretions from the nose and mouth. Immediately assess the heart rate, respiration, and "central" colour (by looking at the lips).

At one minute

If the heart rate is greater than 100 per minute, but respiration is poor, give 100% oxygen and if necessary give a few positive pressure breaths using the paediatric resuscitator bag (or T-piece circuit), mask, and airway.

If the heart rate is less than 60 per minute and respiration is poor, intubate the trachea and ventilate the lungs with oxygen. If intubation is difficult (allow only two attempts), ventilate the lungs with a mask and airway. If in any doubt, use mouth-to-mouth/nose resuscitation.

If the heart rate is less than 50 per minute, an assistant should begin cardiac massage.

Table 8. Essential equipment for neonatal resuscitation

Suction apparatus and catheters
Laryngoscope
T-piece circuit *or* paediatric resuscitator bag and mask *or* bellows, with oxygen reservoir
Oxygen source
Oropharyngeal airways
Tracheal tubes, 2.5 and 3.0 mm, and introducer
Umbilical vein catheter
Fluids: plasma expander, 10% glucose
Drugs: sodium bicarbonate, epinephrine 0.1 mg/ml (1 : 10000)

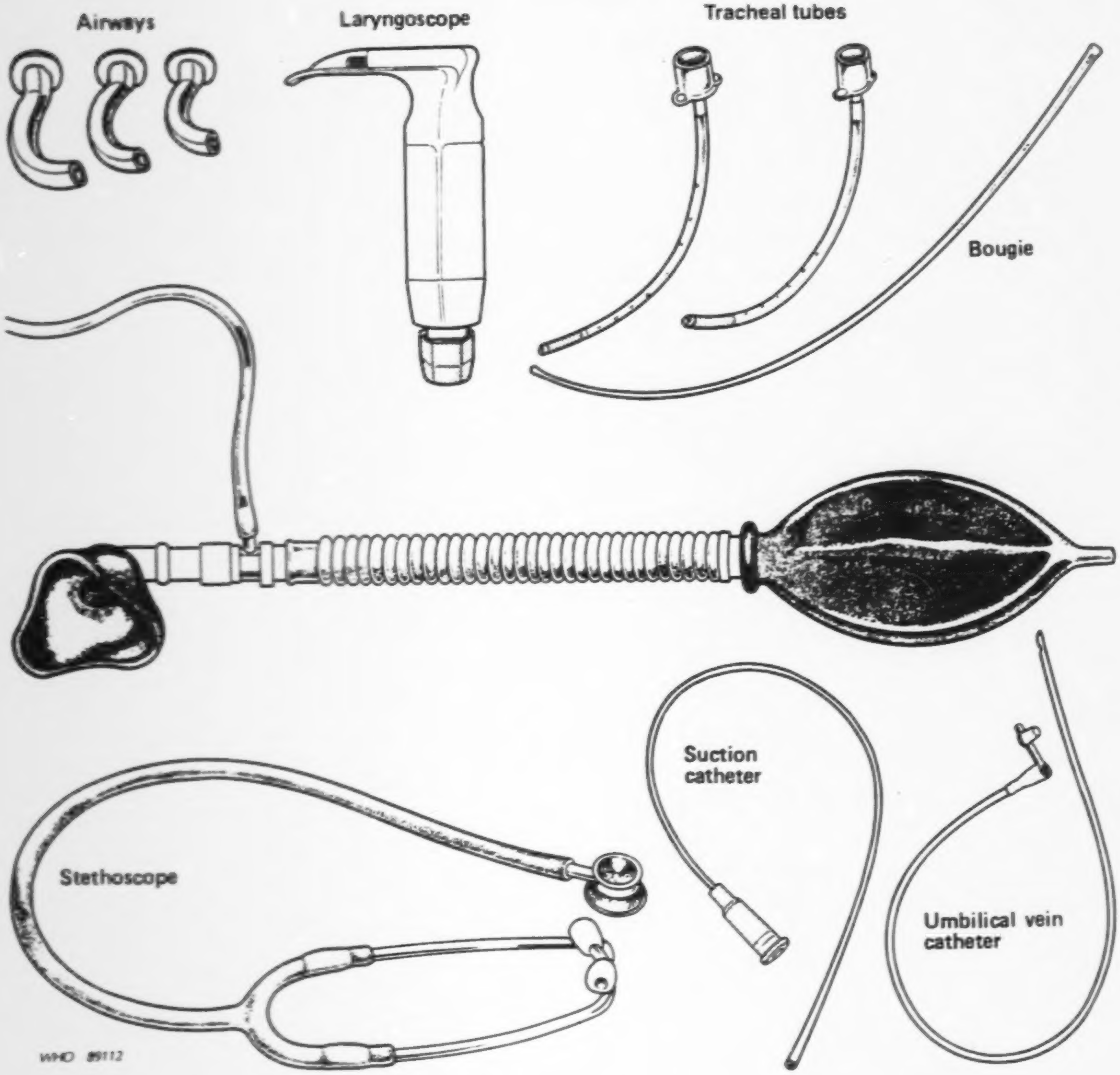
Airways
Laryngoscope
Tracheal tubes
Bougie
Suction catheter
Stethoscope
Umbilical vein catheter
WHO 89112

Fig. 13.4. Some of the apparatus needed for neonatal resuscitation.

At five minutes

Most babies respond rapidly to resuscitation. If the heart rate remains less than 60 per minute despite apparently adequate respiration, consider whether the cause is:

- incorrect intubation
- severe birth trauma
- diaphragmatic hernia
- severe blood loss
- hydrops fetalis
- pneumothorax.

Continue resuscitation and insert the catheter into the umbilical vein. Give sodium bicarbonate (diluted in saline) at 2 mmol/kg of body weight, 10 ml of 10% glucose, and 0.2 ml/kg of body weight of 1 : 10 000 epinephrine.

Specific problems

- *Meconium aspiration*. Mild cases can be treated by sucking out the fluid from the nose and mouth. A nasogastric tube should be used to empty the stomach.

If obvious aspiration has occurred, intubate the trachea and gently suck out the meconium, but do not ventilate. In severe cases the baby may develop respiratory distress, requiring oxygen and antibiotics.

- *Apnoea.* Prenatal causes of apnoea include intrauterine infection and the administration of narcotics to the mother; postnatal causes include nasal obstruction (which can be overcome with an oral airway) or applying excessive suction to the baby's pharynx.
- *Blood loss* can occur as a result of caesarean section, placenta praevia, breech delivery, or twin-to-twin transfusion. The baby will be pale with a tachycardia. Give a plasma substitute or group O Rh-negative blood at 10–30 ml/kg of body weight via an umbilical vein catheter, and repeat this as necessary. The pulse rate should gradually fall to normal.
- *Growth-retarded babies* are susceptible to hypoglycaemia, hypocalcaemia, birth asphyxia, and hypothermia.

14

Important medical conditions for the anaesthetist

Anaemia

Severe anaemia interferes with the body's oxygen transport system by reducing the amount of oxygen that can be carried by the blood as oxyhaemoglobin. This means that, to supply the tissues with adequate amounts of oxygen, the heart must pump more blood — hence the tachycardia, flow murmurs, and heart failure sometimes found in severely anaemic patients. If such a patient is to be subjected to surgery, which may cause blood loss, and to anaesthesia, which may interfere with oxygen transport by the blood, all possible steps must be taken to correct severe anaemia preoperatively. If time is limited, it may only be possible to do this by transfusion, after consideration of the possible benefits and risks.

There is no absolute haemoglobin concentration below which a patient is "unfit for anaesthesia". The decision to anaesthetize a patient depends on the circumstances and the urgency of the need for surgery. Ideally, of course, every patient should have a haemoglobin level "normal" for the community from which he or she comes, but a patient with a ruptured ectopic pregnancy cannot be sent away with iron tablets or even wait for a preoperative blood transfusion. As a rough guide, most anaesthetists prefer not to anaesthetize a patient whose haemoglobin level is below 80 g/litre if the need for surgery is not urgent, especially if serious blood loss is expected.

Remember that "anaemia" is not a complete diagnosis and may indicate that the patient has another pathological condition that has so far gone undetected — perhaps sickle-cell disease or chronic gastrointestinal bleeding from hookworm infection or a duodenal ulcer. The cause of "incidental" anaemia may be far more in need of treatment than the condition requiring surgery. It is therefore important to investigate anaemic patients properly and not to regard anaemia as a "nuisance" for anaesthesia or to assume that it is necessarily due to parasitic infection.

If you are presented with an anaemic patient with an urgent need for surgery, how should you proceed? Remember that the oxygen-carrying capacity of the patient's blood is lower than normal, so avoid drugs and techniques that may make things worse by lowering the cardiac output (for example deep halothane anaesthesia) or by allowing respiration to become depressed. Ether and ketamine have much in their favour, as they do not depress cardiac output or respiration significantly. Oxygen supplementation is desirable for anaemic patients. Blood lost must be replaced with blood, or the haemoglobin concentration will fall further. Ensure that the patient does not become hypoxic during or after the operation.

Haemoglobinopathies

Haemoglobinopathies are inherited abnormalities of haemoglobin production, which are common in some parts of the world (mostly areas where malaria is prevalent) and in black races. A large number of chemical variants of haemoglobin have been detected, but only a few produce serious disease that may influence anaesthesia; the two most important groups of diseases are the sickling conditions, associated with HbSS, HbAS, and HbSC, and the thalassaemias.

Sickling conditions

Sickle-cell haemoglobin differs from normal adult haemoglobin by a single amino acid in the globin chain, but this small change affects the properties of the molecule so that at low oxygen tensions it forms a crystal (tactoid), which distorts the red cell into an abnormal sickle shape. Sickled cells are rapidly haemolysed, so affected people may suffer from a severe haemolytic anaemia. They also block the capillary microcirculation and trigger thrombosis in vessels. Once started, this process tends to become irreversible and finally results in tissue infarction.

People who carry two genes for sickle-cell haemoglobin (homozygotes, HbSS) have the most serious form of disease, called sickle-cell disease. They are severely anaemic and prone to serious infections, and suffer repeated episodes of arterial thrombosis and pulmonary infarction. The high concentration of HbS in the blood of homozygotes means that sickling is constantly occurring at normal venous oxygen tension, and if they become hypoxic or acidotic it will become even more severe. Homozygotes often die young as a result of repeated infarctions, infections, or sudden aplastic anaemia.

People with a single gene for sickle-cell haemoglobin (heterozygotes, HbAS) have the sickle-cell trait. They are clinically normal, but their red cells are likely to sickle if they become hypoxic or acidotic, when they may develop a severe crisis identical to that of a homozygote. It is therefore important to identify heterozygous patients before anaesthesia and surgery and to ensure that they do not become hypoxic or suffer cardiovascular depression, which could lead to acidosis.

Homozygous patients can often be recognized clinically by their poor growth, by haemolytic anaemia (with sickle cells visible in an ordinary blood film), and by evidence of past infarctions, such as cerebrovascular occlusions and pulmonary and bone infarcts. Heterozygotes can be identified only by laboratory tests; their blood film is usually normal with no sickle cells visible, but the presence of sickle-cell haemoglobin can be detected by incubating the blood with a reducing agent (1% hypochlorite) for an hour, after which sickle cells will be seen. Laboratory tests for detecting sickle-cell haemoglobin rely on its solubility differing from that of normal haemoglobin. For full investigation, haemoglobin electrophoresis is necessary, but this will be possible only at a major referral centre.

A second haemoglobinopathy, found mainly in West Africa, is haemoglobin C disease. Homozygotes (HbCC) suffer from a severe anaemia, but the haemoglobin does not in itself cause sickling. In people who carry one sickle-cell haemoglobin gene and one HbC gene (HbSC) the red cells do have a tendency to sickle, which is intermediate between that seen in people with the HbAS and HbSS genotypes.

It is very important to know preoperatively whether a patient carries sickle-cell haemoglobin. Many patients with sickling crises present with clinical signs resembling those of an acute condition that requires emergency surgery, but such patients do not need an operation. Examples of sickling-associated problems that may be falsely diagnosed are:

- bone infarct mimicking osteomyelitis or septic arthritis
- splenic infarct mimicking an "acute abdomen"
- renal infarct causing haematuria.

Patients with sickling conditions who do need surgery and anaesthesia require special care. A thorough preoperative assessment is essential. Patients with sickle-cell disease will probably already have multisystem disease, including possible myocardial damage, pulmonary hypertension, and renal failure, and treatment may be needed for these. As anaesthetist, your aim is to prevent the development of hypoxia, acidosis, depressed cardiac output, hypotension, venous stasis, or hypothermia — any of which could trigger the sickling process. Make sure that sufficient fluids are given preoperatively, and in the operating theatre be generous with fluid replacement (but be careful not to overload patients with sickle-cell disease who may have poor cardiac function). The use of ether or ketamine as the main anaesthetic is suggested, since both these agents maintain a good cardiac output. Oxygen supplementation should be used during and after anaesthesia. Avoid heavy doses of opiates, which may cause respiratory depression, and keep the patient warm at all times. Cold produces venous stasis, and the patient's oxygen requirement will go up if shivering starts.

Cardiovascular diseases

Patients with cardiac disease present a number of problems if they require anaesthesia. The function of the heart, which may well be abnormal to start with, can be further affected by potent drugs that the patient is receiving, such as β-adrenoceptor blockers, digoxin, or calcium-channel blockers. Added to this are the anxiety and catecholamine release that come with an operation, as well as the cardiovascular depression that is, to a certain extent, an effect of all anaesthetic drugs, both local and general. It is not surprising that problems occur from time to time when such patients are anaesthetized.

Ischaemic heart disease

Patients with ischaemic heart disease who need anaesthesia and surgery have a greater-than-average risk of complications. Narrowed coronary arteries need a well maintained perfusion pressure to allow blood to flow to the myocardium. Any degree of hypotension may therefore be very harmful, but so may hypertensive crises, which drastically increase the amount of work the left ventricle has to do, even though blood flow through the coronary arteries cannot be further increased.

No patient should have elective surgery within 6 months of a myocardial infarction; there is a substantial risk of another infarction occurring postoperatively, whether general or conduction anaesthesia is used, and the mortality associated with such infarcts is very high — over 50%. For a patient who requires emergency surgery within 3 months of an infarction, a conduction technique is preferable, with the anaesthetist taking great care to avoid hypotension. A patient with ischaemic heart disease requiring elective surgery should be strongly considered for referral to a larger hospital.

Patients with chronic ischaemia (i.e. those with stable angina pectoris, a previous history of myocardial infarction, or evidence of ischaemia on an electrocardiogram but without symptoms) can be given careful anaesthesia (general or conduction) for elective surgery. A careful preoperative assessment is needed, with a search for evidence of poor myocardial function, for example dyspnoea or cardiac failure, or the presence of dysrhythmias. A full, 12-lead electrocardiogram should be obtained, and X-ray examination of the chest should also be routine. Patients who are in a stable condition while taking drugs should not have their treatment altered or stopped. Measurement of the patient's serum potassium concentration is essential, especially if the patient is taking digoxin or a diuretic. The general principle applies that no patient should have elective surgery if a further preoperative improvement in condition is possible.

If general anaesthesia is chosen, a technique based on intubation and relaxant with IPPV is preferable to deep inhalational anaesthesia, which may cause severe myocardial depression. In many patients with ischaemic heart disease, laryngoscopy can provoke severe tachycardia and dysrhythmias, and many anaesthetists prefer to give an intravenous bolus of lidocaine (1 mg/kg of body weight) about 30 s before laryngoscopy in an attempt to prevent this. During anaesthesia, try to avoid sudden swings in blood pressure, and maintain good oxygenation and ventilation (hence the recommendation for IPPV). Good postoperative analgesia is important, as severe pain can cause hypertension and dysrhythmias. If you have access to an electrocardiograph (ECG) with a continuous display, use it from the time before induction of anesthesia until full recovery; if you have only a paper-writing ECG, you should connect the electrodes to the patient, so that if any clinical signs make you suspect a dysrhythmia during the operation, you can make a rapid diagnosis from a rhythm strip.

Myocardial diseases (cardiomyopathies)

These conditions are characterized by damage to myocardial tissue, and may affect muscular performance, electrical activity, or both. The causes may be:

- nutritional (for example beriberi, alcoholism)
- congenital (fibroelastosis, muscular dystrophy)
- infective (Chagas disease)
- idiopathic.

Most of these conditions present with progressive cardiac dilatation and cardiac failure. Anaesthesia and surgery are then extremely hazardous and, in all but the direst emergency, such patients should be referred for a full cardiac assessment. If anaesthesia is unavoidable, consider the use of a field or nerve block, combined with ketamine if necessary. General and spinal anaesthetics, unless given by an experienced specialist anaesthetist, are best avoided.

Valvular heart disease

Patients with valvular heart disease have impaired cardiac function. You must assess from a medical history and examination how severe the patient's disease is. This requires careful inquiry about the patient's symptoms and exercise tolerance. A patient with mitral valve disease but only mild symptoms will normally withstand anaesthesia well, but severe dyspnoea or cardiac failure points to severe disease and the need for referral. Unfortunately, the management of patients with aortic valvular disease is not so straightforward; they may develop symptoms only in the preterminal phase of their disease. They should certainly not have elective anaesthesia if there is any hint of angina, effort syncope, or blackouts or if there is any clinical, electrocardiographic, or radiographic evidence of left ventricular hypertrophy. For emergencies, use low spinal anaesthesia (taking steps to avoid hypotension) or a nerve/field block as the technique of choice. If general anaesthesia is unavoidable, avoid rapid intravenous induction, which can cause fatal cardiovascular collapse.

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A potential problem in patients with valvular disease is that they may develop bacterial endocarditis as a result of transient bacteraemia from instrumentation in the mouth or other parts of the body, such as the urinary tract. Antibacterial prophylaxis is therefore essential. A high level of antibiotic is required only for the peri-operative period, and for most purposes this can be achieved by penicillin and streptomycin. For an adult, crystalline benzylpenicillin (600 mg, 1 million International Units) mixed with procaine benzylpenicillin (600 mg, 600 000 International Units) should be given intramuscularly with streptomycin (1 g) 30–60 min before surgery. Phenoxymethylpenicillin (500 mg) should be given by mouth or intramuscularly 6 hours later. A commonly used alternative is a single oral dose of amoxicillin (3 g) given 1–2 hours preoperatively.

Hypertension

Elective anaesthesia and surgery are contraindicated in any patient with sustained hypertension and blood pressure greater than 180 mmHg (24.0 kPa) systolic or 110 mmHg (14.7 kPa) diastolic. This degree of hypertension will be associated with clinical signs of left ventricular hypertrophy on chest radiographs and electrocardiograms, retinal abnormality, and possibly renal damage. In an emergency, the same principles apply to the management of a hypertensive patient as to a patient who has had a recent myocardial infarction. Consider a conduction anaesthetic technique and make every attempt to avoid hypotension, which can precipitate a cerebrovascular accident or myocardial infarction. Severely hypertensive patients whose need for surgery is not urgent should be referred.

Patients whose hypertension has been reasonably well controlled can be safely anaesthetized. It is important not to discontinue any regular treatment with antihypertensive drugs, or the patient's blood pressure may go out of control. After a full assessment of the patient, including obtaining a chest radiograph and an electrocardiogram and measuring serum electrolyte concentrations (especially if the patient is taking diuretic drugs), you may carefully use any suitable anaesthetic technique, with the exception of ketamine, which tends to raise the blood pressure. If the patient is receiving treatment with β-adrenoceptor blockers, the treatment should be continued, but remember that the patient will be unable to compensate for blood loss with a tachycardia, so special attention is needed.

If an elective operation is postponed to allow hypertension to be treated, the patient should normally be allowed a period of 4–6 weeks to stabilize before returning for surgery. It is not safe simply to start antihypertensive drugs the day before operation.

Respiratory diseases

Tuberculosis

Tuberculosis is a multisystem disease whose respiratory and other effects may present problems for the anaesthetist. There are firstly the problems of anaesthetizing a patient with a severe systemic illness, who may have nutritional problems and abnormal fluid losses from fever combined with a poor oral intake of fluid and water, and a high metabolic rate requiring a greater supply of oxygen than normal.

Local problems in the lung — the production of sputum, chronic cough, and haemoptysis — may lead to segmental or lobar collapse and hence to inadequate ventilation and oxygenation. Tracheal tubes may quickly become blocked with secretions, so frequent suction may be necessary. In sick patients who cannot cough effectively, a nasotracheal tube may be left in place after surgery or a tracheostomy performed to allow for aspiration of secretions.

Contamination of anaesthetic equipment with infected secretions must also be considered. If you have to anaesthetize a patient with tuberculosis, use either a disposable tracheal tube, which you can then throw away, or a red rubber tube which, after thorough cleaning with soap and water, can be autoclaved. The patient's breathing valve and anaesthetic tubing will also need to be sterilized. Black, antistatic breathing hose can be autoclaved. It is unlikely that the SIB in a draw-over system will be contaminated, but if you sterilize an SIB be careful, as many of these are damaged by autoclaving. If you use a Magill breathing system on a Boyle's machine, the whole system should be autoclaved, as the patient can breathe directly into the bag. If you cannot see how to overcome contamination problems with inhalational anaesthesia, use ketamine or a conduction technique instead.

Asthma

For elective anaesthesia and surgery in a patient with a history of asthma, the asthmatic condition should be under control and the patient should have had no recent infections or severe wheezing attacks. If the patient takes drugs regularly, treatment must not be discontinued. Special inquiry must be made about any former use of steroids, systemically or by inhaler. Any patient who has previously been admitted to hospital for an asthmatic attack should be referred for assessment. Conduction anaesthesia combined with intravenous sedation with small doses of diazepam may be a better choice of technique than conduction anaesthesia alone or general anaesthesia.

If general anaesthesia is necessary, premedication with an antihistamine such as promethazine together with 100 mg of hydrocortisone is advisable. It is important to avoid laryngoscopy and intubation during light anaesthesia, as this is likely to lead to severe bronchospasm. Ketamine is quite suitable for intravenous induction because of its bronchodilator properties. For short procedures, it is advisable to use a face-mask technique after induction and avoid intubation altogether. Use an oxygen concentration of 30% or more in the inspired gas. If intubation is required, deepen the anaesthesia with an inhalational agent and intubate without giving a relaxant. A patient anaesthetized deeply enough to allow laryngoscopy is unlikely to develop bronchospasm as a result of intubation. Ether and halothane are both good bronchodilators, but ether has the advantage that, should bronchospasm develop, epinephrine (0.5 mg subcutaneously) can safely be given (this would be very dangerous with halothane which sensitizes the heart to the dysrhythmic effects of catecholamines). Aminophylline (up to 250 mg for an adult by slow intravenous injection) can be used as an alternative to epinephrine if bronchospasm develops; it is compatible with any inhalational agent.

At the end of any procedure that includes tracheal intubation, extubate with the patient in the lateral position and still deeply anaesthetized; otherwise the laryngeal stimulation might again provoke intense bronchospasm.

Chronic bronchitis

The patient with chronic bronchitis has some degree of irreversible airway obstruction. In taking a history, you should ask about exercise tolerance, smoking, and sputum production. The patient must be told to give up cigarettes completely at least 4 weeks before the operation. Simple clinical tests of lung function may be valuable; healthy people can blow out a lighted match 20 cm from the mouth without pursing their lips and can count aloud in a normal voice from 1 to 40 without pausing to draw breath. The nature of the operation is of great importance; elective surgery on the upper abdomen is contraindicated, since respiratory failure in the postoperative period is likely. Patients needing such surgery must be referred to a hospital where their lungs can be ventilated artificially for 1–2 days postoperatively if necessary.

For emergency surgery, use a technique with intubation and IPPV with added oxygen. Postoperatively, give oxygen at not more than 1 litre/min via a nasal catheter. Be careful with opiates, as the patient may be unusually sensitive to respiratory depression. For upper abdominal analgesia, consider repeated intercostal blocks. With 0.5% bupivacaine these blocks can last 6–8 hours, during which time the patient can breathe and cough up sputum without pain. The patient should of course receive regular chest physiotherapy both before and after operation.

Diabetes

When a diabetic patient needs surgery, it is important to remember that he or she is more likely to be harmed by neglect of the long-term complications of diabetes than from the short-term control of blood glucose levels. Make a full preoperative assessment, looking especially for symptoms and signs of peripheral vascular, cerebrovascular, and coronary disease, all of which are common in patients with diabetes, as is chronic renal failure.

The diabetic patient who needs elective surgery is not difficult to handle. In the short term, the only major theoretical risk is that undetected hypoglycaemia might occur during anaesthesia. In fact most general anaesthetics, including ether, halothane, and ketamine, cause a small and harmless rise in the blood sugar concentration and are therefore safe to use. (There is a widespread but unfounded belief that diabetic patients should not be given ether.) Thiopental and nitrous oxide have little effect on the blood sugar concentration; no anaesthetic causes it to fall.

Diabetic patients can be classified according to whether their diabetes is controlled with insulin (insulin-dependent diabetes or Type I) or by diet and/or oral hypoglycaemic drugs (non-insulin-dependent diabetes or Type II). If the patient's diabetes is controlled by diet alone, you can normally use an unmodified standard anaesthetic technique suitable for the patient's condition and the nature of the operation.

For insulin-dependent patients, ensure that the diabetes is under reasonably good control. On the morning of the operation, do not give the patient food or insulin; this will ensure a normal or slightly elevated blood sugar concentration, which will tend to rise slowly. Measure the blood sugar concentration shortly before anaesthesia. It will probably be 7–12 mmol/litre, but if it is higher than 12 mmol/litre, give 2–4 International Units of soluble insulin intravenously or subcutaneously and measure it again in an hour. Give further doses of insulin as necessary.

As an alternative, if frequent blood sugar measurements are impossible, put 10 International Units of soluble insulin into 500 ml of 10% glucose to which 1 g of potassium chloride (13 mmol) has been added. Infuse this solution intravenously at 100 ml/hour for a normal-sized adult. Continue with this regimen until the patient can eat again and then return to normal antidiabetic treatment. This scheme is simple and will maintain blood glucose levels in most diabetic patients in the range 5–14 mmol/litre; however, regular checks of blood glucose concentration should be made and the regimen changed if necessary. Note that, if glass infusion bottles are used, the dose of insulin will need to be increased by about 30%, as the glass adsorbs insulin. Where several patients are due to undergo surgery on a given day, diabetic patients should be first on the list, since this makes the timing and control of their insulin regimen much easier.

Patients with non-insulin-dependent diabetes controlled with oral hypoglycaemic drugs should not take their drugs on the morning of anaesthesia. Because certain drugs, notably chlorpropamide, have a very long duration of action, there is some risk of hypoglycaemia, so the blood sugar concentration should be checked every few hours until the patient is able to eat again. If difficulties arise with these patients, it may be simpler to switch them temporarily to control with insulin, using the glucose-plus-insulin infusion regimen described above.

Emergency surgery

The diabetic patient requiring emergency surgery is rather different. If the patient's diabetes is out of control, there is danger from both diabetes and the condition requiring surgery. The patient may well have severe volume depletion, acidosis, hyperglycaemia, severe potassium depletion, hyperosmolality, and acute gastric dilatation. In these circumstances, medical resuscitation usually has priority over surgical need, since any kind of anaesthesia attempted before correction of the metabolic upset could prove rapidly fatal. Resuscitation will require large volumes of saline with potassium supplementation (under careful laboratory control). There is no point in giving much more than 4 International Units of insulin per hour, but levels must be maintained either by hourly intramuscular injections or by continuous intravenous infusion. The patient will need a nasogastric tube and a urinary catheter. If the need for surgery is urgent, a conduction anaesthetic technique can be used once the circulating volume has been fully restored. Before a general anaesthetic can be given, the potassium deficit and acidosis must also have been corrected, or life-threatening dysrhythmias are likely. The level of blood sugar is much less important; it is better left on the high side of normal.

Obesity

Obese patients (who may also be diabetic) face a number of problems when anaesthesia is necessary. Obesity is often associated with hypertension — though with a very fat arm the blood pressure is difficult to measure and may appear high when in fact it is not. Because of the extra body mass, the cardiac output is greater than in a non-obese person; more work is also required during exertion, which places greater stress on the heart. The association of smoking, obesity, and hypertension is often a fatal one with or without anaesthesia. Because of the mass of fat in the abdomen, diaphragmatic breathing is restricted and the chest wall may also be abnormally rigid because of fatty infiltration. Breathing becomes even more inefficient when the patient is lying down, so IPPV during anaesthesia is recommended, with oxygen enrichment if possible.

Extra technical problems are found in obese patients. A fat neck makes airway control and intubation difficult, and excess subcutaneous fat leads to difficulty with venepuncture and conduction anaesthesia. Do not give drugs on a weight basis, as this will result in an overdose. For most drugs given intravenously, a 120-kg patient needs only about 130% of the normal dose for an adult of 60–70kg. For general anaesthesia in the obese patient, a technique based on tracheal intubation with IPPV using relaxants is recommended.

Malnutrition

Malnourished patients require special care and should ideally be allowed a period of intensive feeding (beginning gradually) before surgery to enable them to survive the metabolic demands of surgery and then be capable of the process of healing.

Multiple deficiencies may be present in malnutrition. Iron, folate, and vitamin B12 (cyanocobalamin) deficiencies are likely. An initial measurement of haemoglobin concentration may be misleadingly high as a result of dehydration. Other vitamin deficiencies, for example beriberi, may give rise to muscle weakness with consequent respiratory or cardiac failure. Liver function is likely to be depressed, with low levels of enzyme activity resulting in an increased duration of the action of many drugs. Low plasma protein levels mean that oedema, either peripheral or pulmonary, can easily develop in response to what seems a minor fluid overload. If surgery is absolutely necessary in such a malnourished patient, it is probably safer to avoid general anaesthesia and use whatever conduction technique is likely to cause the least physiological disturbance.

Chronic renal failure

Patients with renal failure may be suffering from a variety of related medical problems, including diabetes, anaemia, electrolyte disturbances, hypertension, and chronic acidosis. They may require surgery for problems relating to pyonephrosis, urinary obstruction, or renal and bladder stones. The anaesthetist needs to pay particular attention to the drugs used during anaesthesia, as those normally excreted by the kidney will have an abnormally marked and prolonged action. Problems are most likely to arise with the prolonged action of non-depolarizing relaxants. Gallamine in particular is totally dependent on renal excretion and should never be used in a patient with renal failure. Opiates also depend on the kidney for excretion, so must be used with caution. If the haemoglobin concentration is low it is important to maintain a good cardiac output. For anything but a minor procedure, a urinary catheter should be inserted to monitor urinary output, and a good diuresis should be maintained.

Transmission of infection during anaesthesia and surgery

Patients undergoing surgery have an increased risk of developing infections. Anaesthesia impairs the normal functions of the respiratory system and may result in lung infection if the patient is unable to cough effectively, or if infection is introduced into the respiratory tract by tracheal tubes, suckers, or other objects. Invasive procedures like intravenous cannulation and urinary catheters can be a source of infection. Sick patients may already have a poorly functioning immune defence system and are at special risk.

Among the most feared complications of anaesthesia is the permanent neurological damage that can result from infection or inflammation of the meninges or spinal nerve roots following spinal anaesthesia. It is absolutely essential that all needles and other apparatus used for spinal anaesthesia are first scrupulously cleaned and rinsed and then completely sterilized by autoclaving.

Blood transfusions can be the means of transmitting a number of deadly infections, and the screening processes used on donated blood are never 100% certain. The most feared infections are with HIV which causes AIDS, and hepatitis virus which can cause death from acute hepatitis or chronic hepatitis infection, which has now been linked to the development of liver cancer in later life. Malaria, syphilis, and other diseases can also be transmitted by infected blood. It is vital to ensure that blood is stored properly — blood that has been at room temperature for more than 4 hours (by being left out of the refrigerator, or as a result of an overnight power failure) must be discarded, since unrefrigerated blood is a perfect culture medium and its use involves a grave risk of transmitting septicaemia.

Because of the risk of infection, blood transfusion must be used only when medically necessary and when the potential benefits outweigh the risks (see p. 45). The decision depends on both the patient's condition and the local availability and safety of blood supplies. Where blood supplies are scarce or unsafe, it may be possible to use pre-donation by the patient in elective cases (see p. 45), or to use autologous transfusion in emergencies (see p. 41).

Infection risks to staff

Patients who are infected with any of the organisms listed above may themselves be a risk to other patients or members of the hospital staff. It is vital to have a safe system to prevent infected liquids — blood, urine, gastric contents, faeces, etc. — from becoming a hazard to staff. Safe disposal of needles and other sharp instruments is of primary importance. Never leave syringes attached to needles that have been used on a patient. Try to use plastic infusion cannulae with injection ports that do not require the use of a needle for intravenous injections. Make sure that blood spills are immediately and safely dealt with, and use gloves for all procedures where blood or other body fluids may be spilled. Where blood spillage is likely, gloves, waterproof aprons or gowns, and eye protection are all recommended.

15

Oxygen, gas supplies, equipment, and maintenance

Gas supplies

Oxygen

Oxygen is valuable and sometimes essential during anaesthesia and for treatment of patients with respiratory diseases such as pneumonia and asthma, and it is important to have a sufficient and reliable source of supply. Fortunately, oxygen is widely available, since it is needed for a variety of industrial, in addition to medical, applications. As the same process is used for the production of cylinders of "industrial" oxygen as for cylinders of "medical" oxygen, i.e. the fractional distillation of air, good-quality industrial oxygen is perfectly safe for medical use. It may also be easier to obtain and less expensive, since a price premium is often levied for "medical-grade" oxygen. However, if you obtain oxygen from an unorthodox source, you must check it for purity before use (a portable analyser can be used).

Oxygen cylinders need to be handled carefully because of the fire risk, and also because of their very high internal pressure. Compressed oxygen is not cheap, and efficient and economical use — while still ensuring that the patient receives the maximum benefit — is also important. However, if properly understood, oxygen supplies can be used quite economically. The oxygen concentration of air (21%) generally needs to be increased only to about 40% in order to bring great benefit to the majority of patients who need extra oxygen.

Small or remote hospitals can face problems of logistics and cost in the use of oxygen. In the United Republic of Tanzania, for example, a recent survey showed that 75% of district hospitals had an oxygen supply for less than 25% of the year. A reliable system for cylinder oxygen depends on a good source of supply and reliable year-round transportation. In many countries, oxygen cylinders must be bought rather than rented, and frequent losses of cylinders in transit impose additional costs.

In practice, there are two possible sources of oxygen for medical purposes — cylinders (derived from liquid oxygen) and concentrators (which purifiy the oxygen in air). To manufacture liquid oxygen, large industrial plants cool and liquefy air and distil off the oxygen, which is then again liquefied for storage or pumped into cylinders at high pressure. This method requires a major investment and large amounts of electricity. To use the oxygen thus produced requires a special valve, called a regulator, to release the oxygen in a controlled way, and a flow meter to control the flow. Without a flow meter, the use of oxygen from cylinders is very wasteful; without a regulator it is also extremely dangerous! Although the cost of these items is soon repaid many times over by savings from increased efficiency, many hospitals still do not use them.

Not all oxygen cylinders are the same; there are at least five different sorts of cylinder in use in different countries. As a regulator will fit only one sort of cylinder, it is vital to know what sort is in use before ordering regulators. This information should be obtained from the local oxygen supplier, and should be confirmed by someone with technical knowledge who works in the hospital, e.g. an anaesthetist, chest physician, paediatrician, or fully trained hospital technician.

The system for cylinder oxygen supplies

Getting oxygen to patients who need it requires more than just an oxygen cylinder or two! In fact you must have in place an entire functioning *system*, comprising not only the *apparatus* for oxygen delivery, but also the *people* who operate it (who need to have been trained) and a system of *maintenance*, *repair*, and supply of *spare parts*.

For oxygen in cylinders, such a system includes:

- a factory to produce the oxygen and a source (e.g. sales agent) for the cylinders;
- a transportation system to get the cylinders to the hospital;
- a supply system to ensure that the hospital orders the appropriate amount of oxygen;
- the apparatus used to deliver the oxygen from the cylinder to the patient, which includes:
  - — a suitable regulator;
  - — a flow meter;
  - — oxygen delivery tubing;
  - — a humidifier;
  - — a tube to carry oxygen to the patient's face;
  - — a nasal catheter (or mask) to deliver the oxygen to the patient's airway;
- a person with suitable clinical training to give the correct amount of oxygen in the correct manner to the patients who need it;
- a person with suitable technical training to maintain the apparatus in good condition and to repair it when necessary;
- a financial system capable of paying and accounting for the above.

The reliable supply of oxygen requires planning, training, and maintenance. Any attempt to acquire "just the apparatus" will soon result in misuse and/or breakdowns that waste money and prevent the patients who need oxygen from getting it.

The system for oxygen from concentrators

Oxygen concentrators have been installed in many hospitals where cylinders are not consistently available. Concentrators ensure a more reliable and lower-cost supply of oxygen than cylinders. An oxygen concentrator uses zeolite to separate oxygen from nitrogen in air. The oxygen produced by concentrators is at least 90% pure and can be used in the same way as oxygen from cylinders, and with the same beneficial effects. Oxygen concentrators require much less energy than fractional distillation, and have the additional advantage that oxygen can easily be produced in the operating theatre or at the patient's bedside, provided that there is an electricity supply (a small concentrator uses about 350 W).

Concentrators have been used in industrialized countries for many years for individuals who need purified oxygen at home, primarily because of the dramatic cost savings that can be achieved. The purchase price of a concentrator is about half the cost of a year's supply of oxygen from cylinders, and running costs (for electricity and spare parts) are low.

As for oxygen from cylinders, you need to plan for a complete system of infrastructure, training, apparatus, and spare parts. There is no technology for oxygen supplies — whether from cylinders or concentrators — that can be acquired and

Table 9. At-a-glance comparison of cylinder and concentrator systems

Cylinder system	Concentrator system
Inexpensive to buy	More expensive to buy
Expensive to operate	Inexpensive to operate
Needs year-round supply of cylinders	Needs only electricity
Training and maintenance needed	Training and maintenance needed
Can store oxygen	Cannot store oxygen (provides oxygen only when power supply is on)

expected to continue working without the support of these essential factors. For a system of oxygen delivery based on concentrators, you will need:

- a manufacturer and supplier of concentrators;
- a source of electricity in the hospital (either mains electricity or a generator);
- a supply system to ensure that a sufficient supply of major spare parts is purchased and stored centrally, and a sufficient supply of minor spare parts (e.g. air intake filters) is available at each hospital;
- apparatus to get the oxygen from the concentrator to the patient, which includes:
  - — a flow meter (included in every concentrator);
  - — oxygen delivery tubing;
  - — a humidifier;
  - — a tube to carry oxygen to the patient's face;
  - — a nasal catheter (or mask) to deliver the oxygen to the patient's airway;
- a person with suitable clinical training to give the correct amount of oxygen in the correct manner to the patients who need it;
- a person with suitable technical training to maintain the apparatus in good condition and to repair it when necessary;
- a financial system capable of paying and accounting for the above.

Which system should you choose?

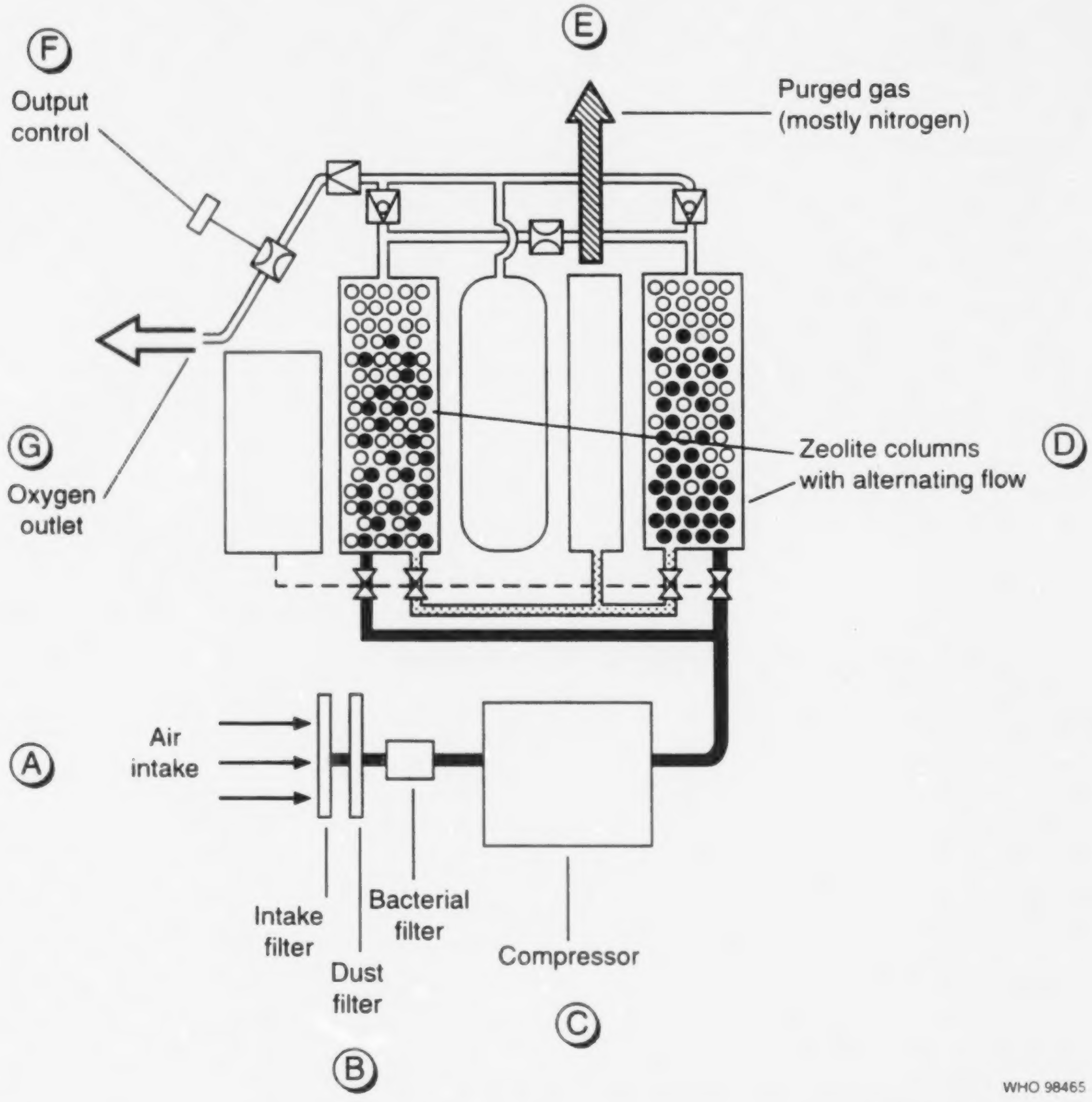
The most important differences between cylinder and concentrator systems are summarized in Table 9.

For remote hospitals that do not have the ability to obtain oxygen cylinders on a regular basis, there is a strong case for introducing concentrators. However, cylinders can supply oxygen during power cuts and concentrators cannot (without electricity, the flow of oxygen will stop within a few minutes). The ideal oxygen-supply system for such hospitals is probably one based primarily on concentrators, but relying on back-up supply from cylinders in case of electricity failure. Details concerning the necessary apparatus for such a system, designed to supply oxygen reliably to up to four children or two adults, are available through WHO (Blood Safety and Clinical Technology) and UNICEF (Procurement Office). Their addresses can be found on p. 132.

How oxygen concentrators work (see Fig. 15.1)

Room air is drawn into the concentrator through a series of filters, compressed to 4 atmospheres, and passed into a column containing zeolite. Nitrogen is adsorbed, but oxygen passes through (as does the 1% argon present in room air). Before the zeolite column becomes saturated with nitrogen, the flow of air is switched to a second column: the first is then vented to atmosphere, and most of the adsorbed nitrogen is discharged. The remainder of the nitrogen is removed

Functioning of the oxygen concentrator


E
Purged gas
(mostly nitrogen)
F
Output
control
G
Oxygen
outlet
Zeolite columns
with alternating flow
D
A
Air
intake
Intake
filter
Dust
filter
Bacterial
filter
Compressor
C
B

WHO 98465

Fig. 15.1. Simplified diagram of an oxygen concentrator. (A) Air intake, (B) filters, (C) compressor, (D) zeolite columns, (E) nitrogen exhaust, (F) output control, (G) oxygen outlet.

by back-flushing the first column with a small flow of oxygen from the second. When the second column approaches saturation the process is reversed. The useful life of the column can be expected to be at least 20 000 hours, which in most situations would give about 10 years of use. The gas emerging from the columns (normal composition: 95% oxygen, 5% argon) passes into a small reservoir chamber, and from there through a flow-control system to the patient. Most small machines can produce a gas flow of up to 4 litres/min with an oxygen concentration greater than 90%. As higher flow rates result in a loss of concentration, most machines are flow-limited to prevent concentration from dropping too low.

Are concentrators reliable?

Domiciliary concentrators have been in regular use for more than 10 years and have in general proved very reliable. They do of course need regular servicing, usually after every 5000 hours of use. Servicing the machines is not complicated and can if necessary be carried out by the user after simple training.

Performance standard for oxygen concentrators

A group of clinicians and engineers under the auspices of the World Health Organization and the World Federation of Societies of Anaesthesiologists has established a recommended Performance Standard that a small concentrator should fulfil in order to be of maximum value in the district-hospital setting. An International Standard for small concentrators has already been published by the International Organization for Standardization (ISO 8359), but relates mainly to safety in use. The Performance Standard described here is designed to ensure that small concentrators are not only safe but able to function properly and reliably in the difficult circumstances sometimes found in district hospitals. A prerequisite of the recommended Performance Standard is that the concentrator meet the ISO standard and designated parts of International Electrotechnical Commission (IEC) standards. In addition, the following criteria should be fulfilled:

- The concentrator must be capable of functioning in adverse circumstances, such as:
  - — ambient temperature up to 40 °C;
  - — relative humidity up to 100%;
  - — unstable mains voltage;
  - — extremely dusty environment.
- The concentrator must pass "military-standard" shock, vibration, and corrosion tests.
- The concentrator must be incapable of delivering an oxygen concentration at maximum output of less than 70%.
- Every concentrator must be supplied with a comprehensive service manual and not less than a 2-year supply of spare parts.[1]

UNICEF can supply concentrators meeting the Performance Standard at a very economical price. For details, write to Procurement Office, UNICEF, 3 United Nations Plaza, NY 10017, USA.

A hospital planning to use oxygen concentrators should consider buying at least two. Remember that no piece of equipment will last for ever, especially if neglected. Hospitals using concentrators need to plan for regular maintenance, order a reserve of spare parts, and assign the task of looking after the machine to a specific individual who has the necessary training. Make sure you buy a machine meeting the recommended Performance Standard, preferably from a manufacturer with local representation in the country in which you work. An up-to-date list of concentrators currently known to meet the recommended Performance Standard is available from Blood Safety and Clinical Technology, World Health Organization, 1211 Geneva 27, Switzerland.

Safe use of cylinders

The oxygen supply from a cylinder must be connected to the anaesthetic apparatus through a suitable pressure-reducing valve (regulator). For larger cylinders this valve is incorporated into the cylinder's pressure gauge; on a Boyle's machine both the gauge and the pressure-reducing valve are part of the machine. When connecting a cylinder to the anaesthetic apparatus, make sure that the connectors are free from dust or foreign bodies that might cause the valves to stick. Never apply grease or oil, as it could catch fire in pure oxygen, especially at high pressure. Remember that an oxygen cylinder contains compressed oxygen in gaseous form, and that the reading on the cylinder pressure gauge will therefore fall proportionately as the contents are used. A full oxygen cylinder normally has a pressure of around 13 400 kPa (132 atmospheres, 2000 p.s.i.). It should always be replaced if the internal pressure is less than 800 kPa (8 atmospheres, 120 p.s.i.), as failure is then imminent.

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[1] A more detailed description of the criteria is available from Blood Safety and Clinical Technology, World Health Organization, 1211 Geneva 27, Switzerland.

Oxygen cylinders are themselves dangerous objects: if they fall over they can injure or even kill. Make sure that cylinders are safely stored and mounted — in storage they can lie horizontally, but in use should be securely fixed in the vertical position to a wall or stand with a restraining strap or chain.

Nitrous oxide

Nitrous oxide was one of the first agents to be used as an inhalational anaesthetic, but because of its low potency it cannot be given as sole anaesthetic agent. When given in combination with other anaesthetics, nitrous oxide reduces the amount of the other agents needed to achieve the required level of anaesthesia. It has few uses other than for anaesthesia and is much more expensive (about 10 times more) than oxygen. Full nitrous oxide cylinders have a pressure of 5200 kPa (51 atmospheres, 750 p.s.i.), but since the cylinder contents are mostly liquid, this pressure is maintained until the cylinder is about 85% used, after which the pressure falls rapidly. Nitrous oxide must always be mixed with oxygen so as to deliver a minimum of 30% oxygen to the patient. The use of an oxygen analyser at the gas outlet is strongly recommended (it is compulsory in many countries) to warn of the delivery of hypoxic gas mixtures.

Minimum anaesthetic equipment for district hospitals

The anaesthetic equipment listed below represents the minimum that a district hospital should possess:

Anaesthetic face masks	• 2 of each size, infant to large adult; total 14
Oropharyngeal airways	• 2 of each size, 00 to 5; total 12
Laryngoscopes	• 2 handles + 3 pairs of blades, or 4 plastic laryngoscopes (2 adult + 2 paediatric) • 12 spare bulbs + 30 batteries (or 8 rechargeable batteries + charger)
Tracheal tubes	• sizes 2.5–10 mm (internal diameter) in 0.5 mm steps, Oxford or Magill or similar, with cuffs only on sizes >6 mm
Urethral bougies	• for use as intubating stylets
Magill's intubating forceps	• (in an emergency, ovum forceps can be used instead)
Tracheal tube connectors	• 15 mm plastic (can be connected directly to the breathing valve), 3 for each tube size
Catheter mounts (sometimes also called tracheal tube connectors)	• antistatic rubber, 4

Breathing hose and connectors	● 2 lengths of 1 metre antistatic tubing ● 4 lengths of 30 cm tubing for connection of vaporizers ● T-piece for oxygen enrichment
Breathing valves	● universal non-rebreathing valves (6 adult + 2 paediatric)
Breathing systems (for continuous-flow anaesthesia)	● Ayre's T-piece system ● Magill breathing system
Self-inflating bellows/bag (SIB)	● 1 for adults + 1 for children
Anaesthetic vaporizers (draw-over type)	● for ether and halothane
Equipment for intravenous use	● needles and cannulas, including paediatric sizes, and an umbilical vein catheter ● infusion sets
Spinal needles	● range of sizes, 18-gauge to 25-gauge
Suction apparatus	
Oxygen supply and delivery system	● concentrator or cylinder-based, with back-up
Standard metric tool kit	● for routine repairs and maintenance
Instruction and repair manuals	● as appropriate, for above-mentioned equipment

Suction apparatus

A reliable sucker is essential and must be available for any general or conduction anaesthetic procedure. A large variety of suction apparatus is available, powered by electricity, by compressed gas, or by hand/foot (Fig. 15.2). Electrical suckers are most convenient to use, provided there is not a power cut. Mechanically operated suckers are a good back-up, both for electrical failures and for use on patients in transit. They can be operated by pedal or by pressing a trigger. Suckers powered by compressed gas are efficient, but not advisable for hospitals where gas supplies may be limited and oxygen is best reserved for patients to breathe. Non-medical compressed air, if available, can serve as a power source.

Test your sucker regularly. A good test is to see how long it takes to deal with 100 ml of thick soup (or equivalent). This will give you an idea of how efficient the sucker will be when used in a patient's pharynx in an emergency.

Storage and maintenance of equipment

Without properly maintained equipment, anaesthesia becomes difficult, dangerous, and sometimes impossible. Unless your hospital has a specially trained technician, the responsibility for maintenance falls on the clinical anaesthetist.

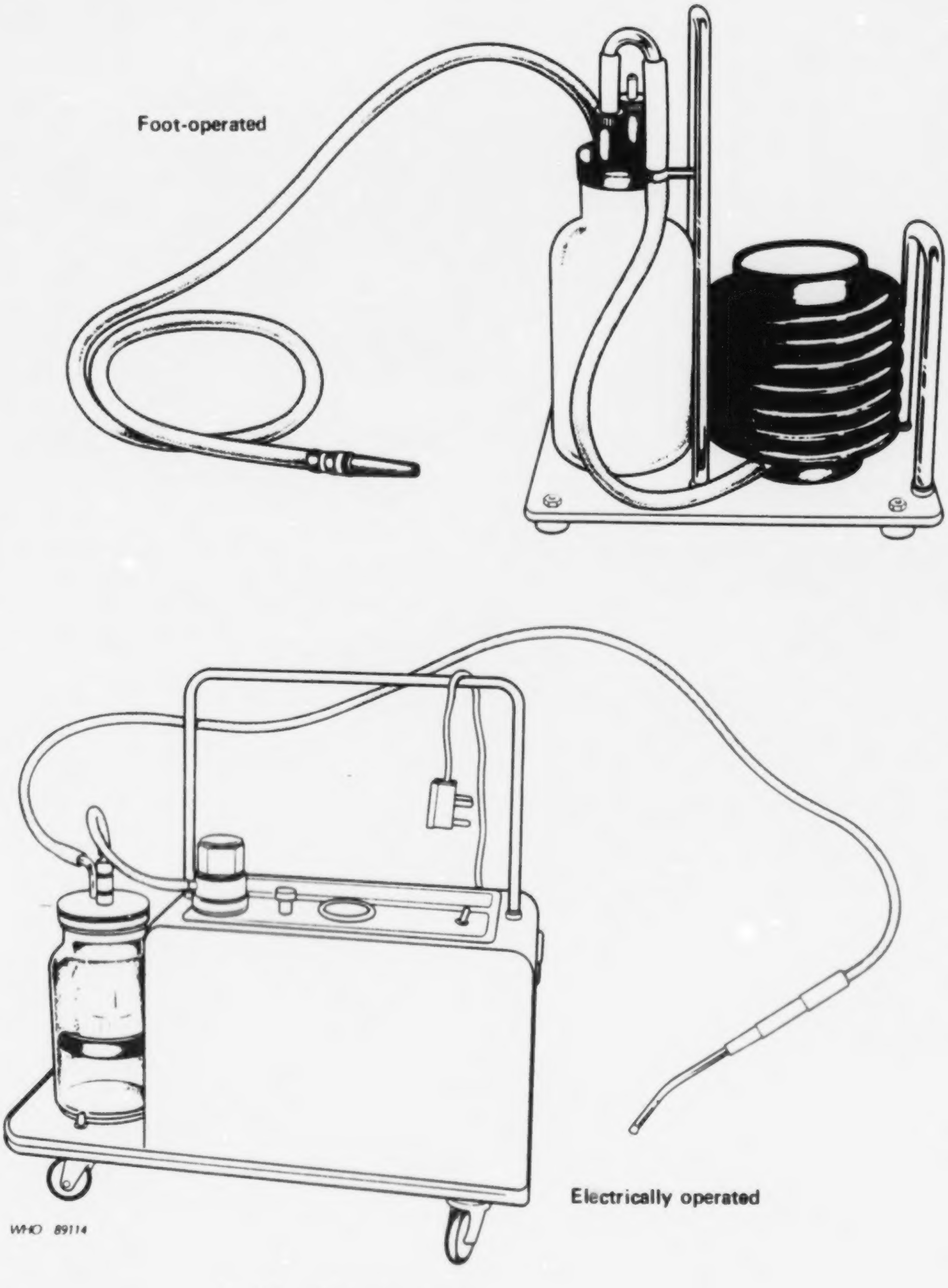

Fig. 15.2. Suction apparatus.

Make sure that your apparatus is properly cleaned after every use. After each anaesthetic procedure, pieces of apparatus that have been in contact with the patient (for example laryngoscope blade, face mask, airway, tracheal tube) should be thoroughly scrubbed with soapy, warm water, rinsed, and allowed to dry in a dust-free place. Formal sterilization of these items is not necessary in most cases. After use on patients with infections, however, apparatus should be cleaned as above and the all-metal or metal-and-rubber items autoclaved, for example, the metal laryngoscope blade (without the bulb) and the rubber airway; other items should be sterilized chemically, with reference to the manufacturer's instructions.

You must establish a secure, dry, cool, and dust-free place in which to store equipment between operating sessions (for example a lockable cupboard).

You must have a detailed inventory listing all the equipment you possess. Anticipate the need for further supplies of items such as batteries, bulbs, and tubes, and order replacements well in advance. Allow at least 6 months for anything that needs to be imported. Check all your apparatus at least once a month. Put bungs in any open-ended vaporizers to keep out dust and insects, and join breathing hoses end-to-end in a circle. Wipe down your apparatus regularly with a dilute, soapy antiseptic solution. If your vaporizers are to be unused for a week or more, drain off the anaesthetic agents (but not the water). Drain all vaporizers at least once a month to remove debris and antioxidants contained in the anaesthetic formulations, to avoid parts of the vaporizer becoming stuck.

Check your equipment regularly for leaks, both by inspecting it and by pressurizing it (do this by hand for an SIB by squeezing the bag or bellows after putting a bung in the valve).

No piece of apparatus will work indefinitely without attention. Try to anticipate what will be needed in terms of spare parts, tools, etc. before the need actually arises. Make sure you have an instruction manual, and where possible, a service manual for every piece of apparatus for which you are responsible. Spare manuals are normally available at little or no cost from the manufacturers. If you do not know the manufacturer's address, WHO will be able to assist you (Blood Safety and Clinical Technology, World Health Organization, 1211 Geneva 27, Switzerland).

If you plan to carry out maintenance of the equipment yourself, first read the entire section in the manual to check whether any replacement spare parts will be needed; if they are, make sure they are in stock before you start.

Establish contact with your national referral hospital for the servicing of equipment. Many draw-over vaporizers are relatively simple to service and do not need to be sent back to the manufacturer, but do not attempt to service vaporizers or oxygen concentrators yourself unless you have been fully trained to do so.

Annex 1

Checklist for draw-over anaesthetic apparatus

Keep a copy of this list by your anaesthetic apparatus. You must fully check all apparatus before beginning anaesthesia.

Oxygen cylinder and flow meter
Turn on supply of gas from cylinder, and check pressure and flow. Also check spare cylinder.

Oxygen concentrator (if available)
Check inlet filter for dust and clean if necessary.

Switch on concentrator. Check alarms.

Set oxygen flow to 4 litres/min and check concentration (should exceed 90% oxygen within 5 min of switch-on).

At least once a month check the hour clock to determine whether a machine service is due.

Check back-up system in case of power failure (either a reserve cylinder of oxygen or back-up electricity).

Oxygen reservoir
Check for proper assembly of T-piece, and make sure that air inlet is unobstructed.

Vaporizer
Check that the vaporizer is filled (using only stocks of anaesthetic in their original containers). Check that connections fit, and set dials to zero.

Self-inflating bag/bellows
Check connections and, if applicable, position of magnet on bellows.

Breathing and connecting hoses
Check connections and correct assembly of breathing system (see Fig. 7.7, p. 63).

Check breathing hoses weekly for cracks or signs of rubber deterioration.

Breathing valve
Test the valve by breathing through it yourself. Check it visually; the bobbin or valve leaflets should move during breathing. Air should pass freely along the correct path.

Check for leaks
Squeeze the bag or bellows while using your hand to block the connector that joins the breathing valve to the patient. No air should escape.

Make sure that you have:

- face mask of suitable size
- oropharyngeal airway of suitable size
- tested laryngoscope and spare
- tracheal tube of suitable size (test cuff by inflating)
- tested suction apparatus
- table or trolley that can be tilted head-down
- all drugs you may need.

NEVER INDUCE ANAESTHESIA UNLESS AN ASSISTANT IS PRESENT.

Annex 2

Checklist for continuous-flow (Boyle's) anaesthetic apparatus

---

Keep a copy of this list by your anaesthetic apparatus. You must fully check all apparatus before beginning anaesthesia.

Emergency equipment

You *must* have a suitable resuscitation device, for example a self-inflating bag or bellows, to ventilate the lungs of the patient in case your gas supply fails.

Oxygen supplies

For machines fitted with cylinder-only supply

Turn on the oxygen supply from the cylinder in use and check the pressure. Turn on the supply from the reserve cylinder, check the pressure, and turn it off again. Check that you have a third cylinder available to replace the cylinder in use when it is exhausted.

For machines fitted with a piped gas supply

Check the source of your piped gas supply (most likely a large cylinder which may be outside the operating theatre). Check that you have a full cylinder of oxygen fitted to your machine in case the piped supply fails.

All machines

Turn off all gas supplies except one oxygen cylinder or piped supply. Open *all* flow meters. Oxygen should flow through only one flow meter (rotameter) tube (the oxygen one!). *If this does not happen, do not use the machine.*

If your machine has an *oxygen-failure warning device*, test it as follows:

> Turn on the gas supply from one oxygen cylinder (pipeline disconnected if fitted) and one nitrous oxide cylinder (if fitted).
>
> Open flow meter taps to give a flow of oxygen (and nitrous oxide also if fitted) of 5 litres/min.
>
> Turn off the oxygen supply at the cylinder. If a functioning warning device is fitted, an alarm should sound as the oxygen flow meter bobbin starts to fall (this may take a few seconds). On some machines, oxygen failure automatically cuts off the nitrous oxide supply also.
>
> *After the test remember to open the oxygen cylinder valve again.*

Avoid using a machine that does not have a functioning oxygen-failure warning device. If you have no alternative, you must record the oxygen cylinder pressure every 5 min throughout anaesthesia and change to a fresh cylinder when the cylinder pressure drops below 1500 kPa (15 atmospheres, 220 p.s.i.).

You must never begin anaesthesia with a machine that has only a single source of oxygen, i.e. only one cylinder or one pipeline.

Nitrous oxide

Check the pressure in the nitrous oxide cylinder in use and in the reserve cylinder. If the pressure in a nitrous oxide cylinder at room temperature is less than 5200 kPa (51 atmospheres, 750 p.s.i.), the cylinder is less than 15% full.

Flow meters

Inspect visually for cracks. Make sure that the bobbins do not stick in the tubes.

Emergency oxygen

Locate and turn on the emergency oxygen (bypass) button or tap. A high flow of oxygen should be delivered from the gas outlet. Note that this supply does not pass through the oxygen flow meter.

Vaporizers

Check that all vaporizers are firmly connected and filled with the correct anaesthetic agent (from stocks of anaesthetic in their original containers). Check that all filling ports are firmly closed, and that concentration dials are set to zero. A Boyle's bottle should have both the lever and the plunger pulled up.

Leaks

Check your machine once a month for leaks (or immediately, if you suspect one) by "painting" suspect areas with soapy water and watching for bubbles.

Breathing system

Check for correct assembly (see Fig. 7.12, p. 71).

Make sure that you have:

- face mask of suitable size
- oropharyngeal airway of suitable size
- tested laryngoscope and spare
- tracheal tube of suitable size (test cuff by inflating)
- tested suction apparatus
- table or trolley that can be tilted head-down
- all drugs you may need.

NEVER INDUCE ANAESTHESIA UNLESS AN ASSISTANT IS PRESENT.

Annex 3

Anaesthesia record

You should keep a record of every anaesthetic that you give. The specimen record chart shown opposite could be combined with a preoperative checklist (see Fig. 5.1, pp. 46–47) and a postoperative instruction sheet.

Anaesthesia Record

Date	Age	Weight	BP	Hb g%

Hospital No. ....

Surname ....

First Name ....

Ward .... Blood group ....

Premedication	Effect

Anaesthetist	Surgeon	Operation

ANAESTHETIST'S NOTES; including: relevant history/clinical findings/drugs/allergies.

ANAESTHETIC TECHNIQUE

TIME	DRUG	Total Dose
Chart each dose as given 1		
2		
3		
4		
5		
6		

40 300
35 250
30 200
25 150
°C
100
80
60
40
30
20
10
0

EVENTS

REMARKS

I.V. fluids

Blood loss

WHO 89059

Annex 4
Drugs used in anaesthesia

Aluminium hydroxide
Atropine
Bupivacaine
Diazepam
Epinephrine
Ether (diethyl ether)
Gallamine
Halothane
Ketamine
Lidocaine
Methohexital
Morphine
Nalorphine
Naloxone
Neostigmine
Nitrous oxide
Pethidine
Prilocaine
Promethazine
Propofol
Sodium bicarbonate
Sodium citrate
Thiopental

Names and addresses of local suppliers and agents

(List any useful local addresses here.)

Index

Note: Page numbers in bold type refer to main entries; italicized page numbers refer to illustrations.

Abdomen
  children **110**
  injuries **23**
  preoperative assessment 45, *47*
  relaxation for surgery 96, *97*
  suitable anaesthetic technique 104
Acetylcholine **84–85**
Acute blood loss, replacement guidelines **41–42**
Adrenaline, cardiac arrest 35
β-Adrenoceptor blockers 120, 122
Airways
  artificial *5–6*, **5**, 13, 15, **25–26**, **133**, 138, 140
  care of 3, *4–9*, **4–14**, *11–13*
    anaesthetized patients **26–31**, *27–28*, *30*
    burn injuries **23**
    cardiac arrest 33, 35
    children **109–110**, *110*
    during transportation 20–21
    head injury **21–22**
    intravenous induction 53
  laryngeal mask **5**, *7*, 14
  nasopharyngeal **5**, 6
  obstruction 26, **27–29**, 106
  oropharyngeal *5–6*, **5**, 15, **133**, 138, 140
  preoperative assessment **44–45**
  see also Breathing; Ventilation
Alcuronium **85**
Allergies **106**
Alveolar nerve, block **95–96**, *96*
Ambu valves *58*, 62, *62*, 64, 69
Aminophylline 123
Amoxicillin 122
Anaemia 41, 99, **118**
Anaesthesia
  choice of technique **103–106**
  complications 44, **106**, 126
  minimum equipment **133–134**
  range of techniques 73, *74*
  stages of **79–80**
  see also Conduction anaesthesia; General anaesthesia;
    Ketamine; Spinal anaesthesia; Techniques
Anaesthetized patients **25–35**
  airway protection **26–31**, *27–28*, *30*
  general management **25–26**
  thermal injury protection **26**
Analgesia
  anaesthesia 51, 79–80
  burn injuries 23, 24
  chest injuries 23
  critically ill patients 20
  ether 79
  fractures 23
  intercostal nerve block 96, *97*
  ketamine **82**
  opiate drugs 48, **83**
  postoperative **108**
Ankle, nerve block **92–93**, *94*
Anorexia, burn injuries **24**
Antacid drugs **49**
Antagonists
  benzodiazepines 82
  opiate drugs 31, **83**
  relaxants 75, 84
Anti-emetic drugs **49**
Antibiotics 45, 121–122
Anticoagulant drugs 87, 99
Antihistamines 123
Aortic valvular disease 121
Apnoea
  neonates **117**
  suxamethonium 44
Apparatus **57–72**, *58–63*
  checks **51–52**, 56, 71–72, **137–140**
  contamination 122
  continuous-flow *55*, **56**, **68–72**, *69–72*
  draw-over **54**, *55*, **57–68**, *58–63*, *65–66*
  leaks 136, 140
  maintenance 57, 72
  oxygen **129–136**, *131*
  sterilization 122–123
  storage 72
  suction **134**, *135*, 138, 140
  tracheal intubation 7, *8*
  see also Equipment
Arteries, accidental thiopental injection **52–53**
Artificial airways *5–6*, **5**, 13, 15, **25–26**, **133**, 138, 140
  care of teeth **25–26**
Artificial ventilation *see* Ventilation
Asepsis 88, 99
Asphyxiation 4
Assessment
  before anaesthesia **44–49**, *46–47*
  body fluids **39–40**
  burn injury estimates 23–24
  critically ill patients 3–4, 20
  emergency surgery **76**
  ischaemic heart patients **120–121**
  neonates **115–116**
  postoperative **108**
  severely injured patients **21–24**
  surgical blood loss **41**
  tracheal intubation 10
  treatment effects 3, **19–20**
Asthma 30, **123**
Atropine 48, 54, 75
  cardiac arrest 35
  children 110
  ether 79
  ketamine 73, 81
  neostigmine 85
  premedication dose **49**
Autoclaving 123
  equipment 122–123, 136
  sterile fluid production 43
Autologous transfusion **41–42**, 115, 126
Automatic lung ventilators **70–71**
Autotransfusion 45, 126
Axillary block, brachial plexus **93–95**, *95*
Ayre's T-piece **111**, *112*

Babies *see* Infants; Neonates
Bacterial endocarditis **121–122**
Barbiturates
  accidental thiopental injection **52–53**
  intravenous **52–53**, **81**
Benzodiazepines **82–83**
Benzylpenicillin 122
Bleeding *see* Blood loss
Blood
  peripheral flow **32**
  spillage 127
  storage 126
  volume **36**
Blood loss
  acute, replacement guidelines **41–42**

- Blood loss *(continued)*
  - caesarean section 114
  - children **111**
  - control of **17**
  - during surgery 41
  - head injuries 21, 22
  - intra-abdominal **23**
  - intravenous replacement fluid *38*, **42–43**
  - neonates **117**
- Blood pressure **122**
  - during anaesthesia **32**
  - during pregnancy **113**
  - fluid loss 39
  - intravenous induction 52
  - spinal anaesthesia 99, **101**
  - *see also* Circulation, management
- Blood transfusion
  - caesarean section 114
  - infection transmission **40–42**, 45, **126**
  - need for **40–42**
  - preoperative need assessment **40–42**, 45
  - *see also* Autologous transfusion; Autotransfusion
- Body fluids
  - burn injuries **24**
  - clinical assessment **39–40**, 44
  - description **36–38**, *37 38*
  - loss 41, 44
  - replacement solutions **19**, **36–43**, *38–39*
- Bone infarct 120
- Bougies, urethral 9, **133**
- Boyle's bottle 56, **68–69**, *69–70*
- Boyle's machine *see* Continuous-flow anaesthesia
- Brachial plexus, axillary block **93–95**, *95*
- Bradycardia **31**, 110
- Brain
  - cardiac arrest damage 33, 34
  - function 3
  - injuries 30
- Breathing
  - anaesthetized patients **26–31**
  - failure to re-start 31
  - inadequate 3, *15–16*, **15–17**
  - oxygenation 7, 10, 13, **15**, **17**, *26–27*
- Breathing systems **134**, 137, 140
  - continuous-flow anaesthesia 56, **69–71**, *71–72*
  - draw-over anaesthesia 54, 57, *58*, *62–63*, **62–67**, *65–66*
  - Magill 56, *69*, **69**, *71*, 123
  - preoperative checks 52
- Breathing valves **134**, **137**
  - infants 111
  - universal *18*, 57, 62–63, *62*, **64–65**
- Bronchitis, chronic 30, **123–124**
- Bronchodilation 79
- Bronchospasm 123
- Bronchus intubation, accidental 9, 19, 30
- Bupivacaine **87**
  - contraindications 98
  - nerve blocks 96
  - spinal anaesthesia 98, 99
- Burn injuries **23–24**
  - intravenous replacement fluid *38*, **42–43**
  - suxamethonium contraindication 84
  - within surgery 26

- Caesarean section 99
  - field block *91*, **91**
  - general anaesthesia **113–114**
  - spinal anaesthesia **114–115**
- Calcium channel blockers 120
- Carbon dioxide, retention 27, 29–30, 32
- Cardiac arrest, drill **33–35**, *34*
- Cardiac massage 20, **33–34**, *34*
- Cardiac system
  - depression of 106
- Cardiac system *(continued)*
  - disease 45, *47*
  - dysrhythmias 80, 86, 106
  - output 32
  - preoperative checklist *47*
- Cardiomyopathies **121**
- Cardiorespiratory arrest **33–35**
- Cardiovascular system
  - anaesthetized patients **31–33**
  - diseases **120–122**
  - ether 79
  - halothane 80
  - opiate drugs 83
- Catecholamines 79, 80
- Catheter mounts **133**
- Central nervous system 86, 106
  - *see also* Brain; Spinal anaesthesia; Spinal injuries; Spinal needles
- Charts, record-keeping **141–142**
- Checklists
  - anaesthesia equipment **71–72**, 134, **137–140**
  - preoperative assessment *46–47*, 48
- Checks
  - compressed gases 52
  - continuous-flow apparatus 56
  - preoperative **51–52**
- Chest
  - injuries **23**
  - surgery 104
- Children
  - abdomen **110**
  - anaesthesia **109–113**
  - blood pressure **32**
  - bradycardia 31, 110
  - burn injuries 23
  - circulation **111**
  - heart rate 110, 111
  - intravenous access **33**
  - ketamine 53, 73, **82**
  - mouth-to-mouth ventilation **15**
  - premedication 48
  - preoperative fasting **48**
  - resuscitation *33*, **33**, **42**
  - tracheal intubation 7, 9, **109–111**, *110*
  - ventilation with self-inflating bellows/bag 17, 64
  - *see also* Infants; Neonates
- Chloroform 81
- Chronic bronchitis 30, **123–124**
- Chronic renal failure **126**
- Cinchocaine 99
- Circle breathing system 70, *72*
- Circulation
  - children **111**
  - management 3, **17–19**
  - peripheral **32**
  - volume restoration **17–19**
- Circumcision **91–92**, *92*
- Cleaning, apparatus 72, 135–136
- Cocaine 88
- Coma, head injury **21–22**
- Combustion risks, operating theatres **67–68**
- Complications, anaesthesia 44, **106**, 126
- Compressed gases 50, 52
- Concentrators, oxygen **67**, 74–75, 128, **129–132**, *131*, 136, **137**
- Conduction anaesthesia 2, **86–102**, 103
  - asthmatic patients 123
  - contraindications **87–88**
  - drug dosages **87**
  - hypertensive patients 122
  - malnourished patients 126
  - precautions, general **88**
  - premedication 48
  - safety **106**

- Conduction anaesthesia *(continued)*
  - specimen techniques **88–102**
  - *see also* General anaesthesia
- Continuous-flow anaesthesia (Boyle's machine) **50**, *55*, **56**, **68–72**, *69–72*
  - apparatus 2, **68–72**, *69–72*
  - apparatus checklist 134, **139–140**
  - infants **111**, *112*
  - oxygen analyser 56, **69**, 133
  - vaporizers 68, *70*
- Contraindications
  - bupivacaine 98
  - conduction anaesthesia 87–88
  - diazepam 108
  - epinephrine 92
  - gallamine 126
  - halothane 123
  - ketamine 122
  - muscle relaxants 104
  - spinal anaesthesia 99
  - suxamethonium 84
- Controlled ventilation, infants 111
- Convulsions 86, 106
- Crash induction, emergency surgery **77–78**
- Cricoid cartilage 109
- Cricoid pressure 14, 77, *78*, 114
- Cricothyroid injection **88–89**, *89*
- Critically ill patients
  - assessment **3–4**, **20**
  - transportation 3, **20–21**
- Crush injuries, suxamethonium contraindication 84
- Cyanosis 15, 19–20
- Cylinders
  - nitrous oxide **133**
  - oxygen 67, **128–130**, **132–133**

- Dehydration
  - laboratory investigations **39–40**
  - malnourished patients 125
  - replacement fluids *38*, **42–43**
  - sodium overload 38
  - symptoms **39**
- Delivery
  - forceps-assisted **113–114**
  - operative at term **113–115**
- Dental block **95–96**, *96*
- Desflurane 80
- Diabetes **124–125**
- Diarrhoea, fluid replacement *38*, **42**
- Diastolic pressure 32
- Diathermy, risk to patient 26, 68
- Diazepam **82–83**
  - contraindications 108
  - premedication doses **49**
- Diethyl ether *see* Ether
- Differential block 86
- Digital nerve block 92, *93*
- Digoxin 120
- Disease transmission, blood transfusion **40–41**, 45, **126–127**
- Domiciliary oxygen concentrators 129, **132**
- Dosage
  - antibiotics for bacterial endocarditis 121–122
  - atropine **49**, 85, 110
  - child anaesthesia 110–111
  - conduction anaesthesia 87
  - diazepam 49
  - ether 79
  - field blocks 90–91
  - halothane 56, 80
  - insulin 124
  - intravenous regional anaesthesia 98
  - ketamine **53–54**, 73–74, 81–82
  - local anaesthetic drugs 87
- Dosage *(continued)*
  - methohexital 53
  - metoclopramide 49
  - morphine 48
  - neostigmine 85
  - obese patients 125
  - opiates as anaesthesia supplement 83
  - pethidine 48
  - postoperative analgesics 108
  - premedication drugs 48–49
  - propofol 53
  - simple infiltration 89
  - sodium citrate 49
  - spinal anaesthesia 98
  - suxamethonium 84
  - temazepam 49
  - thiopental **52–53**, 81
- Drains, chest injuries 23
- Draw-over anaesthesia 2, 50
  - adding oxygen **65–67**
  - advantages 2, 50
  - apparatus **54**, *55*, **57–68**, *58–63*, *65–66*
  - breathing systems 57, *58*, *62–63*, **62–67**, *65–66*
  - checklist **137–138**
  - infants **111**, *112*
- Drills
  - cardiac arrest **33–35**, *34*
  - failed tracheal intubation 14
- Drugs **79–85**, **86–87**
  - anaesthetic combinations 50–51, *51*
  - cardiac arrest 35
  - general anaesthetic **50–51**, *51*, **79–85**
  - list of 143
  - local anaesthetic **86–87**
  - premedication **48–49**
  - respiratory depression **29–31**
  - *see also* Antagonists; Specific drugs
- Dysrhythmias, cardiac 80, 86, 106

- ECG *see* Electrocardiograms
- Ectopic pregnancy, ruptured 41, **115**
- Elective surgery, blood transfusion 40, 45
- Electricity supply
  - oxygen apparatus 129, 130
  - suction apparatus 134
- Electrocardiograms (ECG) 20, 121, 122
  - cardiac arrest 34
  - during anaesthesia 32
- Electrolyte therapy **36–43**
- Emergency surgery 103
  - anaemic patients **118**
  - caesarean section 114
  - chronic bronchitis patients **123–124**
  - diabetic patients **125**
  - gastric contents **76–78**, *78*
  - general anaesthesia **76–78**, *78*
  - myocardial infarction 120
  - preoperative fasting **48**
  - rapid sequence induction **77–78**
  - tracheal intubation 104
  - valvular heart disease **121–122**
- EMO vaporizers 54, **57–61**, *58–61*
- Endocarditis, bacterial **121–122**
- Endoscopic surgery 104
- Endotracheal intubation *see* Tracheal intubation
- Enflurane 80
- ENT surgery 104
- Epinephrine 80, **87**, 89
  - cardiac arrest 35
  - contraindications 92
  - field block 90–91
  - neonatal resuscitation 116
  - nerve block 94–96
  - simple infiltration 89

Equipment
  checks **51–52**, 56, 71–72, **137–140**
  clinical use **57–72**, *58–63*
  conduction anaesthesia **88**
  contamination 122
  minimum for district hospitals **133–134**
  neonatal resuscitation **115**, *116*
  patient transportation **21**
  sterilization 122–123, 135–136
  tracheal intubation *7*, *8*
  see also Apparatus
Ergometrine 114
Erythrocyte volume fraction **41**, **45**
Ether 51, 75, **79–80**
  anaemic patients 118
  asthmatic patients 123
  continuous-flow induction 56
  diabetic patients 124
  draw-over induction 54, 56
  explosion risks 67
  operative delivery 114
  sickling conditions 120
Ethyl chloride 81
Examination, before anaesthesia **44–48**, *46–47*
Expiratory valves *see* Heidbrink valves
Expired air, lung ventilation **15**
Explosion risks **67–68**
Extubation
  emergency surgery 77, 78
  general inhalational anaesthesia 75
  muscle relaxants 85
Eye care, during anaesthesia **25**

Face masks **133**, 138, 140
  continuous-flow anaesthesia 56
  draw-over anaesthesia 54, 57
  ether 79
  mouth-to-mouth ventilation 15
Failed tracheal intubation **10–14**
  causes **13**
  drill **14**
Family history, anaesthesia reactions 44
Fasting
  babies 110–111
  larynx anaesthesia 88
  preoperative 44, **48**, **51**
Femoral nerve block 23, 97, *98*
Femoral shaft, fractures 97
Fetus, protection during anaesthesia 113
Field blocks *90–92*, **90–92**
Fire risks, oxygen **67–68**, 132–133
Flail segment, chest injuries 23
Flow meters 128, 140
Fluid-electrolyte therapy **36–43**, *38*
Fluids
  body **36–38**, *37–38*
    burn injuries **24**
    clinical assessment 39–40, 44
    loss **41**, **44**
    replacement solutions **19**, **36–43**, *38–39*
Forceps-assisted delivery **113–114**
Fractures
  femoral shaft 97
  major **23**
  pain relief 20, 23
  patient transportation 20
  ribs 96, 97

Gallamine **85**
  contraindications 126
Gases
  compressed 50, 52
  continuous-flow machines 50, 68, 71–72
  supplies **128–133**
Gastric contents
  aspiration 5, 6, 106
  emergency surgery **76–78**, *78*
  pregnant women 113
  premedication 48
  regurgitation 29
General anaesthesia 2, **50–56**, *55*, **73–85**, 104
  asthmatic patients **123**
  bodily heat loss 26
  corrective fluid therapy **39–40**
  diabetic patients 124
  drugs **50–51**, *51*, **79–85**
  emergency surgery **76–78**, *78*
  inhalational **74–76**, **79–80**, 104
  ischaemic heart disease 121
  ketamine 53, **73–74**, **81–82**
  obese patients 125
  operative delivery **113–114**
  patient position 25, *26*
  planning **104–105**, *105*
  respiration monitoring **26–27**, *27*
  safety **106**
  specimen techniques 73–78
    with artificial ventilation 74–75
    with spontaneous breathing 75
  total intravenous 76
  see also Conduction anaesthesia
Glasgow Coma Scale **21–22**
Glucose 37, 111, 116
Groin surgery 104
Guidelines
  blood transfusion **40–42**
  relaxant use **85**

Haemoglobin
  anaemia **118**
  chronic renal failure 126
  malnourished patients 125
  preoperative assessment **40–41**, 45
  sickling conditions **119–120**
Haemoglobinopathies **119–120**
Haemopneumothorax **23**
Haemorrhage *see* Blood loss
Haemothorax 41
Hallucinations 54, 82
Halothane 26, 75–76, 80
  continuous-flow induction 56
  contraindications 123
  draw-over induction 54
Hartmann's solution 19, 36, 41, 99, 114
Hazards
  diathermy 26, 68
  infection transmission 40, 45, **126–127**
  see also Risk; Safety
Head
  injuries **21–22**
  surgery 104
Head-down position 25, 26
Headache, postspinal **101–102**, 115
Heart disease
  preoperative ECG 32
  spinal anaesthesia 99
  surgery complications 41
  see also Cardiomyopathies
Heart rate
  anaesthetized patients **31**
  children 110, 111
  during anaesthesia **31**
  neonates **115**
  resuscitation 20
Heat loss, unconscious patients **26**
Heidbrink valves **64**, *65*, 69, 71
Heparin 53
Hepatitis 40, 45, 126

Hernia, inguinal field block *90*, **90–91**
History taking
  fluid loss 39
  preoperative assessment 44, 48
    checklist *46–47*
HIV *see* Human immunodeficiency virus
Human immunodeficiency virus (HIV) 40, 45, 126
Hydrocortisone 52, 123
Hypertension 120, **122**
  obesity 125
  preoperative assessment 45
Hyperthermia, malignant 44, 82
Hypoglycaemia **110–111**
Hypotension 19
  caesarean section 114
  during pregnancy 113
  general anaesthesia 106
  ischaemic heart disease 120
  local anaesthesia 86
  spinal anaesthesia 99, **101**
Hypothermia
  during anaesthesia 26, 31
  infants **110**
Hypovolaemia 19, 20, 39, 99
Hypoxia
  airway obstruction 26, 29
  cardiac arrest 34
  postoperative 106

Identification, oxygen cylinders **67**
Immobilization, fractures 20, **23**
Induction of anaesthesia **51–56**, **75**, 80
  benzodiazepines 82
  emergency surgery 77–78, *78*
  halothane **80**
  inhalational **54–56**, *55*
  intramuscular **53–54**
  intravenous **52–53**
  ketamine 81–82
  operative delivery **114**
  preoperative checks **51–52**
  technique choice 52
  thiopental **81**
  trained assistance 51
Industrial oxygen 66, 128
Infants
  body fluids 36
  continuous-flow anaesthesia **111**, *112*
  draw-over anaesthesia **111**, *112*
  growth-retarded 117
  heart rate 20
  hypoglycaemia **110–111**
  hypothermia **110**
  infusions
    during surgery 41
    intra-osseous route *33*, **33**, **42**
  intubation **110**
  lidocaine dosage **87**
  premedication 110
  preoperative fasting 51
  resuscitation *33*, **33**, **42**
  tracheal intubation 76–77
  see also Children; Neonates
Infarction, myocardial 120
Infection transmission **40–41**, 45, **126–127**
Inferior alveolar nerve block **95–96**, *96*
Infiltration anaesthesia 104
  field blocks *90–92*, **90–91**
  simple **89**
Infusions
  infants *33*, **33**, 41, **42**
  ketamine 74, **82**
Inguinal hernia repair *90*, **90–91**
Inhalational anaesthesia **50–56**, *55*
Inhalational anaesthesia (*continued*)
  drugs **79–80**
  techniques **74–76**
  see also General anaesthesia
Inhalational induction 28, **54–56**, *55*
  continuous-flow apparatus *55*, **55**
  draw-over apparatus **54–55**, *55*
Injuries, severe **21–24**
Insulin 124
Intercostal nerve block **96**, *97*, 123
Intermittent positive pressure ventilation *see* IPPV
International Standards
  oxygen concentrators **132**
  oxygen cylinders **67**
Interstitial compartment, body fluids **36–37**, *37*
Intra-osseous infusion, infant resuscitation *33*, **33**, **42**
Intracellular compartment, body fluids *37*, **37–38**
Intracranial pressure 106
Intramuscular induction **53–54**
  ketamine **73**
Intrathoracic surgery 104
Intravascular compartment, body fluids **36**, *37*
Intravascular injection, accidental 106
Intravenous access, before anaesthesia 33
Intravenous anaesthesia **81–82**
  ketamine 53, **73**, **81**
  regional 26, **97–98**
  total **76**
Intravenous induction **52–53**
  accidental artery injection **52–53**
  benzodiazepines **82**
Intravenous infusion 17
  body fluid replacement **36–40**, *38*, **42**
  burn injuries **24**
  cardiac arrest 34
  clear fluids during surgery 41
  equipment **134**
  preoperative checks 52
  resuscitation **19**
  sterile fluids production **43**
Inventories, equipment 136
IPPV (intermittent positive pressure ventilation) 17, 75, 82, 86
  apparatus 62, 64–65, 69
  chronic bronchitis patients 123
  ether 79
  infants 111
  ischaemic heart disease 121
  obese patients 125
  respiratory insufficiency 31
  severe injuries 23
  suxamethonium 84
Ischaemic heart disease **120–121**
Isoflurane 80

Ketamine 53, **73–74**, **81–82**
  anaemic patients 118
  as sole anaesthetic 73–74
  asthmatic patients 123
  burn injuries 24
  caesarean section 114
  children 111
  contraindications 122
  intramuscular induction **53–54**
  intravenous induction **53**
  sickling conditions 120
  total intravenous anaesthesia 76
Kidney damage 106

Laboratory investigations, dehydration **39–40**
Laparotomy 79
Laryngeal mask airway **5**, *7*, 14
Laryngeal spasm **28–29**, 81

Laryngoscopes **133**, 138, 140
  use of *8*, **8**, 14
Laryngoscopy **89**
  care of teeth **25–26**
  ischaemic heart disease 121
Larynx
  children **109–110**, *110*
  oedema **109–110**, *110*, 114
  topical anaesthesia **88–89**, *89*
Leaks, apparatus 71–72, 136, 140
Lidocaine 52, **87**, 88–89
  cardiac arrest 35
  field blocks 90–91
  intravenous regional anaesthesia 98
  nerve blocks 92–97
  operative delivery 114
  simple infiltration 89
  spinal anaesthesia 98
Limb surgery 104
Lingual nerve block 96
Lithotomy position 25
Liver damage 106
Low forceps delivery **114**
Lung function, tests 123
Lung ventilation *see* Ventilation
Lung ventilators, automatic 70–71

Magill breathing systems 56, *69*, **69**, *71*
  autoclaving 123
Magill's intubating forceps **133**
Maintenance, equipment 57, 72, 129, 132, **134–136**, **137**
Major surgery 41, 104
Malaria **126**
Malignant hyperthermia 44, 82
Malnutrition **125–126**
Management, cardiac arrest **33–35**
Manuals, instruction and repair 134, 136
Meconium aspiration **116–117**
Metabolic acidosis 19
Metabolic rate, children **110**
Methohexital **53**, **81**
Methohexitone *see* Methohexital
Methoxyflurane 81
Metoclopramide **49**
Midazolam 76, **82–83**
Mitral valve disease 121
Monitoring
  anaesthetized patients **26–27**, *27*, **31–33**
  children **111–113**
Morphine 26, 51, **83**
  postoperative **108**
  premedication dose **48**
Mouth-to-mouth ventilation *15*, **15**
Mucous membranes, topical anaesthesia **88–89**, *89*
Muscle relaxants **83–85**
  antagonists 75
  contraindications **85**, 104
  ether 79
  general anaesthesia 51, **74–75**
  guidelines for use **85**
  halothane 80
  ketamine anaesthesia 73–74
  non-depolarizing **84–85**
  potentiating drugs 31
  respiratory depression 30–31
  reversal **75**
  suxamethonium **84**
  tracheal intubation 6, 10, 17
Myocardial diseases **121**
Myocardial infarction 120

Nalorphine 31, 83
Naloxone 31, 83
Nasogastric feeding, burn injuries **24**
Nasopharyngeal airways **5**, *6*
Neck
  injuries **22**
  surgery 104
Needles 127
Neonates
  body fluids 36, *37*
  resuscitation 114, **115–117**, *116*
  tracheal intubation 7, *9*
  see also Children; Infants
Neostigmine 31, 75, **84–85**
Nerve block 20, 23, 86, **92–97**, *93–98*, 104
Nerves, peripheral **26**
Neuromuscular transmission **84**
Nitrazepam **82–83**
Nitrogen, oxygen concentrators 129, 130–131
Nitrous oxide 2, 50, 56, 68, **133**, **140**
Non-depolarizing relaxants **84–85**
Non-steroidal anti-inflammatory drugs (NSAIDs) **83**

Obesity **125**
Obstetrics
  caesarean section *91*, 91, 99, **113–115**
  ether 79
  fetus protection during anaesthesia 113
  halothane 80
  ketamine 81
  operative delivery at term **113–115**
  preoperative fasting **48**
  ruptured ectopic pregnancy **115**
  see also Pregnancy
Oedema
  child intubation **109–110**, *110*
  laryngeal 23, **109–110**, *110*, 114
  traumatic **38**
Oesophageal stethoscope **27**, *28*
Oesophagus, tracheal tube misplacement 9–10, 14
Operating tables 25, 52, 138, 140
Operating theatres, combustion risks **67–68**
Operative delivery at term **113–115**
Opiate drugs 51, **83**
  antagonists 31
  operative delivery 114
  postoperative **108**
  premedication **48**
  renal failure 126
  severe burns 24
  sickling conditions 120
Oral rehydration salts (ORS) **42**
Oropharyngeal airways *5–6*, **5**, 15, **133**, 138, 140
ORS *see* Oral rehydration salts
Overdose
  benzodiazepines **82–83**
  opiate drugs **83**
Oxford inflating bellows bag *16*, *58*, *63*, **64–65**, *65*
Oxford miniature vaporizer (OMV) 54, **57**, *58–59*, **60**, *61*
Oxygen 50
  anaemia 118
  analysers 56, **69**, 133
  apparatus checklist **137**, **139**
  burns therapy 23
  caesarean section 91, 114
  circle systems 70
  concentration of air 128
  continuous-flow systems 56, 68
  cylinders **67**, **128–130**, **132–133**
  draw-over systems 54, 56, **65–67**, *66*
  fire/explosion risks **67–68**, 132–133
  flow meters 128, 140
  inhalational induction 54, 56
  postoperative care 107

Oxygen (*continued*)
  regulators 128–129, 132
  resuscitation **17**
  sickling conditions 120
  supplementation **74–75**
  supplies **128–133**
Oxygen concentrators **67**, 74–75, 128, **129–132**, *131*, 136, **137**
Oxygenation
  mouth-to-mouth **15**
  signs of adequate *26–27*
  tracheal intubation 7, 10, 13, **17**
Oxytocic drugs 114

PAC draw-over vaporizer 54, 57, *60*, **60**, **62**, 64–65
Paediatric anaesthesia *see* Children; Infants; Neonates
Pain
  burn injuries 23
  control **107–108**
  intravenous induction 52–53
  postoperative **107–108**
Pancuronium 85
Paradoxical respiration 27, 29
Paralysis, muscle relaxant-induced 31
Parasitic infection 118
Patient assessment *see* Assessment
Patient positioning 4–5, 25, 26
  child anaesthesia **109**
  operative delivery **113**, **114**
  postoperative 107
  spinal anaesthesia **98–99**
  spinal injuries 22
  tracheal intubation 7, 9, 13
Patients, preoperative reassurance 45, 47
Penicillin 122
Performance Standard, oxygen concentrators 67, **132**
Perineum surgery 104
Peripheral blood flow 32
Peripheral nerves **26**
Pethidine 51, **83**
  postoperative **108**
  premedication dose **48**
Pharmacology
  ether **79–80**
  halothane **80**
Phenoxymethylpenicillin 122
Physiological saline 36, 41, 114
Planning, general anaesthetic techniques **104–105**, *105*
Plasma expanders 37, *38*, 43
Pneumothorax **23**, 96
Pop-off valves *see* Heidbrink valves
Postoperative care **107–108**
Potassium chloride 35
Pre-eclampsia 114
Preoperative procedures **51–52**
Pre-oxygenation **74–75**
Pregnancy
  anaesthesia during **113**
  ruptured ectopic 41, **115**
  see also Obstetrics
Premedication
  conduction anaesthesia 88
  drug dosages **48–49**
  infants 110
  ketamine anaesthesia 73, 74
  opiate drugs 83
Preoperative assessment **44–49**, *46–47*
  checklist *46–47*, 48
  see also Assessment
Prilocaine **87**, 98
Promethazine 123
Propofol **53**, 76
Pulse oximetry 32

Rapid sequence induction, emergency surgery **77–78**, *78*
Record-keeping
  anaesthesia 2, 106, 108, **141–142**
  fluid status 31
  postoperative care **108**
Recovery areas **107**
Regional anaesthesia 26, **97–98**
Regulators, oxygen 128–129, 132
Rehydration, water loss **42**
Relaxants *see* Muscle relaxants
Renal failure 20, **126**
Renal infarct 120
Repair, oxygen apparatus 129
  see also Apparatus, maintenance
Replacement solutions, body fluid loss **19**, **36–43**, *38–39*
Respiratory system **26–31**, *27–28*, *30*
  airways obstruction **27–29**, 106
  anaesthetized patients, monitoring **26–27**, *27*
  depression of 106, 107
  diseases of 45, *47*, **122–124**
  insufficiency **29–31**
Respiratory tract, burn injuries 23
Resuscitation **15–21**
  cardiac arrest **33–35**
  diabetic patients **125**
  equipment 139
  hypovolaemia 20
  infants, intra-osseous infusion *33*, **33**, **42**
  intravenous fluids **19**
  local anaesthesia toxicity **86**
  neonates 114, **115–117**, *116*
  oxygen enrichment **17**
  patient stabilization 20
  preoperative apparatus checks 52
  when to abandon **21**, 22
Ribs, fractured 96, *97*
Ring block **92**, *93*
Ringer's lactate solution *see* Hartmann's solution
Risk
  blood transfusion **40–42**, 45, 126
  compressed gases 50
  operating theatre fires/explosions **67–68**
Ruptured ectopic pregnancy 41, **115**
Ruptured spleen 41

Safety
  anaesthesia 2, **86–87**, **106**
  apparatus checks **71–72**
  oxygen cylinders 128, **132–133**
Secretion suppression, atropine **48–49**
Sedatives **49**, **88**
  see also Specific drugs
Self-inflating bellows/bag (SIB) **15–17**, *16*, *19*, **134**, 137, 139
  breathing monitoring 27
  cardiac arrest 34
  child surgery 111
  clinical use 57, *58*, 63, *63*, **64–65**, *65*, 71
  sterilization 122–123
Sepsis 106
Seroflurane 80
Service, equipment 132, 136, 137
SIB *see* Self-inflating bellows/bag
Sickle-cell disease 118, **119**
Sickling conditions **119–120**
Smoking 123, 125
Sodium bicarbonate 116
Sodium citrate **49**
Sodium overload 38
Solutions
  fluid replacement **19**, **36–43**, *38–39*
  oral rehydration salts **42**
Spare parts, apparatus/equipment 72, 129, 132, 136

Spinal anaesthesia **98–102**, *100*, 104
  anaemia **99**
  complications **101–102**, 106, 126
  contraindications **99**
  corrective fluid therapy **39–40**
  emergency surgery 76
  operative delivery **114–115**
  pregnant patients 113
Spinal injuries **22**
Spinal needles 134
Spleen, ruptured 41
Splenic infarct 120
Stabilization, post-resuscitation 20
Staff, infection risks **127**
Stages, anaesthesia **79–80**
Standardization, oxygen cylinders **67**
Sterile fluids, production **43**
Sterilization, equipment 122–123, 135–136
Steroids 23, 123
Stethoscopes, oesophageal 27, *28*, 111
Storage
  blood 126
  equipment 72, 136
  ether 79
  oxygen cylinders 133
Streptomycin 31, 122
Succinylcholine *see* Suxamethonium
Suction apparatus **134**, *135*, 138, 140
Supine hypotensive syndrome **113**
Supplies, gases **128–133**, **139–140**
Surgery
  blood/fluid loss estimation **41**
  choice of anaesthesia **103–104**
  diathermy hazards 26, 68
  infection transmission **126–127**
  pre-induction 51
Suxamethonium 74, 75, 76, 77, **84**, 85, 86
  apnoea **44**
  burn injuries **24**
  contraindications 84
  failed intubation 13
  laryngeal spasm 29
  operative delivery 114
Symptoms, water/electrolyte loss **39**
Syphilis 40, 126
Systolic pressure 32

T-piece system 17–19, *66*, **66–67**
  child surgery **111**, *112*
  induction **54**
  oxygen supplementation 74–75
Tachycardia **31**
Techniques
  choice of **103–106**
  conduction anaesthesia **88–102**
  field blocks *90–92*, **90–92**
  general anaesthesia **73–78**
  ketamine anaesthesia **73–74**
  nerve blocks 86, **92–97**, *93–98*
  range of **73**, *74*
  spinal anaesthesia **98–102**, *100*
  tracheal intubation 7–10, *11–13*
Teeth, during laryngoscopy **25–26**
Temazepam 49, **82–83**
Tests
  lung function 123
  tracheal intubation **14**
Tetracaine 99
Thermal injury protection, anaesthetized patients **26**
Thermocompensation valves 58–60, *58*, *61*
Thiopental 51, **52–53**, 75–76, 77, **81**
  accidental artery injection **52–53**
Thiopentone *see* Thiopental
Thrombophlebitis 82
Thrombosis 33
TIVA *see* Total intravenous anaesthesia
Tool kits 134, 136
Topical anaesthesia, mucous membranes **88–89**, *89*
Total intravenous anaesthesia (TIVA) **76**
Tourniquets 26, 95, 97–98
Toxicity
  conduction anaesthetics 106
  local anaesthetics **86–87**
Tracheal intubation 5, **6–14**, *11–13*, 17
  asthmatic patients 123
  burn injuries 23
  children 7, 9, **109–111**, *110*
  chronic bronchitis patients 123
  draw-over induction **54**
  emergency surgery **76–77**, 104
  equipment 7, *8*
  failed **10–14**
  general anaesthesia 74–75, **104**, *105*
  head/neck injury **22**
  inhalational induction 54
  main bronchus entry 9, 19, *30*
  oesophageal misplacement 9–10, 14
  operative delivery 114
  oxygenation 7
  relaxants 6, 10
  technique 7–10, *11–13*
  tests **14**
  with spontaneous breathing **75**
Tracheal tubes 133, 138, 140
  cardiac arrest 34
  children **109–110**
  draw-over anaesthesia 57
  insertion **8–10**, 29, *30*
  removal **29**
Tracheostomy 23
Training, use of oxygen apparatus 129, 130
Transfusion, autologous **41–42**
Transportation
  critically ill patients 3, **20–21**
  patients with spinal injuries 22
Traumatic oedema *38*
Trichloroethylene **80**
Tuberculosis **122–123**
Tubocurarine **85**

Unconscious patients **25–35**
  assessment **3–4**
  breathing **26**
  cardiovascular system **31–33**
  general management **25–26**
  head/neck injury **21–22**
  heat loss **26**
  respiratory obstruction **27–29**
Universal breathing valves *18*, 57, 62–63, *62*, **64–65**
Urethral bougies 9, **133**
Urine 32, *38*

Vacuum extraction, operative delivery **113–114**
Vagolytic antisialogogue drugs **49**
Valves
  continuous-flow systems 68, *69*, **69**
  draw-over systems 57, 58–60, *58*, *61–62*, **62–65**, *65*
  oxygen cylinders 132–133
  see also Thermocompensation valves; Universal breathing valves
Valvular heart disease **121–122**
Vaporizers
  checklist **137**, **140**
  continuous-flow anaesthesia 68, *70*
  draw-over anaesthesia **57–62**, *58*, **134**
  maintenance 136, 137
Vasoconstrictor drugs 87
Vecuronium 85

Venous pressure **32**
Ventilation *15–16*, **15–17**
  artificial 74–75
  children 110, 111
  general inhalational anaesthesia 74–75
  mouth-to-mouth *15*, **15**
  opiate overdose 83
  with self-inflating bellows/bag **15–17**, *16*, *19*, **64**
  see also IPPV
Volatile agents **79–81**
Vomiting
  fluid replacement *38*, **42–43**
  postoperative 79

Warnings
  oxygen risks **67–68**
  relaxant use **85**
Water
  body fluids 36–38
  burn injuries **24**
  see also Fluids

X-ray examination 23, 45, 120

Zeolite, oxygen concentrators 129, 130, *131*

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165